Cunninghamia

A journal of plant ecology for eastern Australia

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Cunninghamia

A journal of plant ecology for eastern Australia

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Allan Cunningham, botanist and explorer (1791–1839)

Cover: Aerial photos of the upper Herbert River floodplain, North Queensland, in 1943 (black & white) and 2006 (colour) showing clearing of former rainforest and sclerophyll vegetation, (see Kemp et al. pages 285–329)

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The role of currents in the dispersal of introduced seashore plants around Australia

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Abstract: The aim of this study was to assess the role of currents in the dispersal of seashore species with buoyant propagules. Four introduced species which have now attained a wide distribution in southern and eastern Australia were used as indicators: *Cakile edentula, Cakile maritima* (Brassicaceae), *Euphorbia paralias* (Euphorbiaceae) and *Arctotheca populifolia* (Asteraceae). None arrived in Australia unaided, as all early collection localities are near ports and early long-distance dispersal within Australia was often due to shipping.

Buoyancy and viability of propagules were tested to assess dispersal and colonisation potential. Propagule spread was analysed using information from herbarium specimens and fieldwork. A progression of herbarium specimen collection dates could often be explained by regional current regimes, as revealed by stranding locations of drift bottles and drift cards. The eastward spread of *Euphorbia paralias* from King George Sound, Western Australia, correlated well with stranding patterns of drift bottles released south of the Sound. The colonisation by *Arctotheca populifolia* of the southern extremity of the Eyre Peninsula and the south-east of South Australia was achieved through fruits carried from Western Australia by the Leeuwin Current. These and other congruencies between patterns of spread and the results of drifter releases are analysed and discussed.

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> *We know remarkably little about long-distance transport of the propagules in water, although there are reports of strandline plants having travelled great distances (Guppy 1906; Ridley 1930). (Davy & Figueroa 1993)*

Introduction

In 1979 I found a colony of the daisy *Arctotheca populifolia* in South Australia at the south-western tip of the Eyre Peninsula more than 800 km from the nearest location of this naturalised species in Western Australia. It occurred to me that introduced species, by virtue of being foreign to the native flora, could be used as markers to analyse the role of sea currents in propagule dispersal. I checked herbarium specimen collection details and found distribution patterns that correlated with the general circulation in the oceans around Australia (Heyligers 1983, 1984).

In this paper I analyse the dispersal histories of four, now widespread, introduced species and assess what these reveal about the role of near- and offshore currents for plant dispersal. *Cakile edentula* (Bigelow) Hook. and *Cakile maritima* Scop. (Brassicaceae) were accidentally introduced during the 19th century (Rodman 1974, 1986), while *Euphorbia paralias* L. (Euphorbiaceae) and *Arctotheca populifolia* (P. Bergius) Norlindh (Asteraceae) arrived during the early decades of the 20th (Heyligers 1983, 1989a) (Fig. 1).

Currents and wind are the main dispersal agents; currents because of the buoyancy of the propagules, wind because of its influence on drifting objects, as well as its capacity to move propagules over bare sandy surfaces. Before the advent of radio-tracked buoys, drift bottles and drift cards were used to study ocean currents (Russell 1894; Anon. 1968a; Marshallsay & Radok 1972). Their application in oceanography suffered the drawback that only points of release and stranding were known — no information on deeper currents was obtained. Nowadays, they are still used for specific purposes, e.g. research on dead seabird strandings (Wood 1996) or marine organisms with a buoyant phase in their development (Vaux & Olsen 1961; Anon. 1968b; Walker & Collins 1982; Collins & Walker 1985; Olsen & Shepherd 2006, Petrusevics 1990, 1991). The outcomes from drift bottle and card studies are also relevant to the dispersal of buoyant plant propagules. A significant difference between plant propagules and bottles or cards is that the latter are released from known positions, while the former first have to become sea-borne. Storm surges that erode foredunes, or breach sandbars closing off coastal lakes will carry propagules into the sea. Offshore winds can push fruits and seeds down the beach and out to sea, where rip currents may contribute to the start of the floating phase. Another important difference is that while stranded bottles or cards can be picked up and reported by any beachcomber, an inconspicuous, washed-up plant propagule first needs to establish a plant, if not a small population, before being noticed by a knowledgeable person.

Methods

Propagule buoyancy and longevity

Cakile and *Arctotheca populifolia* samples were collected in 1984–85 along the South Coast of New South Wales, with additional samples obtained in Western Australia and South Australia and from plants grown from cuttings. The main sample of *Euphorbia paralias* was collected in 1985 by Parks Victoria staff at Norman Bay on the south-west coast of Wilsons Promontory, Victoria. Other samples came from Three Mile Beach on the east coast of the Promontory, from the Sir Richard Peninsula, South Australia, and from Dalmeny, New South Wales. Tests were started shortly after samples were collected and the number of samples tested was 9 of *Cakile edentula*, 15 of *Cakile maritima*, 6 of *Euphorbia paralias* and 12 of *Arctotheca populifolia* plus 13 from plants grown from cuttings.

Samples were stored in paper envelopes at room temperature. To test buoyancy, propagules were put in jars with seawater and, initially, numbers remaining afloat were assessed daily; later, the interval between inspections lengthened until it became one or two years for truly long floaters. Viability was tested at the start of buoyancy experiments; during subsequent tests the viability of stored ('dry'), floating and sunken propagules was assessed. These tests were of an exploratory nature, sometimes done with a small number of propagules. Moreover, the number of propagules used in any one buoyancy test limits how many propagules can subsequently be used for viability testing. Ideally, I would use at least 50 propagules for a buoyancy test and 10 or 20 dry, floating and sunken propagules for viability testing. In practice, and especially in the case of long floating propagules, it became a matter of balancing the number used for viability testing against how many to leave to continue the buoyancy test. Nonetheless, the outcomes should give at least an indication of what one may expect to happen in nature.

Historical evidence of spread

The early collections of all four species were made when far fewer people lived in Australia and collecting activity was less intense, especially in remote areas. Therefore, I tested the possible influence of remoteness by checking the pre-1950 records for six common native Western Australian coastal species and found that even in the early days collecting had not been confined to centres of population but also had happened in isolated locations. This gives reasonable confidence that, if any of the introduced species dealt with in this paper had been present in an area long before it was first collected, it would have been collected earlier. Hence, my axiom has been to assume that a directional progression of early collection dates, separated by large gaps, was a true indication of dispersal by sea.

During the 1980s and 1990s I visited many Australian herbaria and the Herbarium of the Royal Botanic Gardens, Kew (U.K.), to obtain specimen data. Each species was

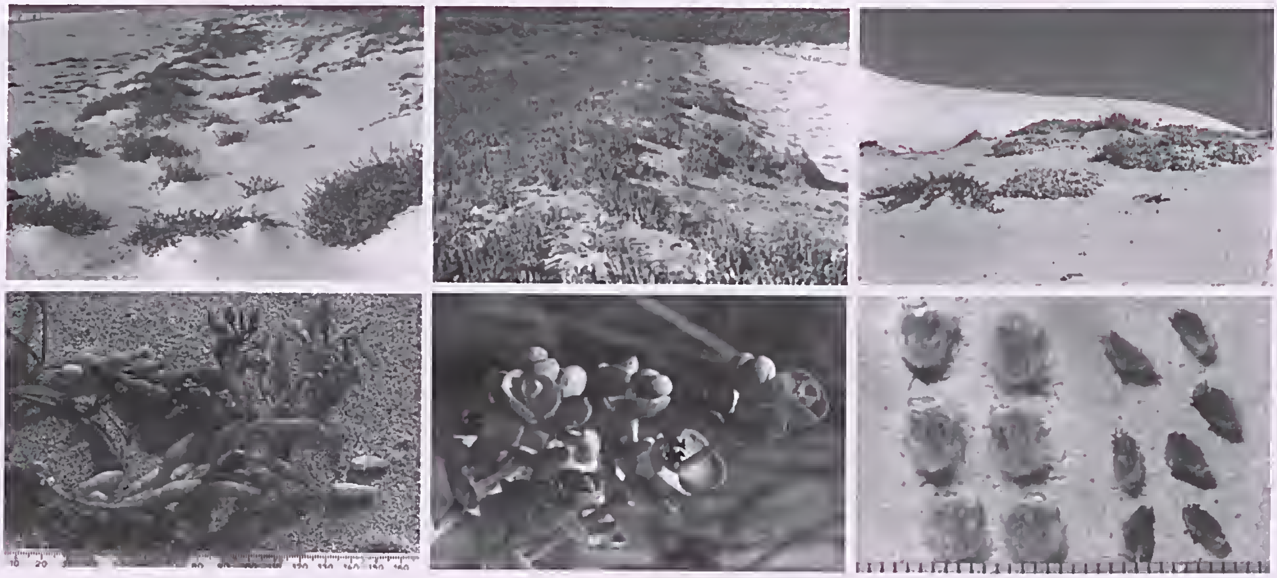

Fig. 1. Pictorial introduction to the four species discussed in this paper. **Left column:** a hummocky strandline dune in southern New South Wales formed by plants of *Cakile edentula* (left and centre) and *Cakile maritima* (right) impeding the movement of sand along the upper beach; the lower photo shows the two-segmented fruits of *Cakile edentula* (top) and *Cakile maritima*. **Centre column:** *Euphorbia paralias* on the foredune at Norman Bay, Wilsons Promontory, where it contributed to the stabilisation of the dune, and part of an inflorescence with fruits that 'explode' when mature and scatter their three round seeds. **Right column:** *Arctotheca populifolia* (centre and at right) in drift sands near Mungo Brush, where the species was first collected in New South Wales. The fruits (achenes) of the western form (left) are compared with those of the eastern form in the lower picture.

sorted by collection dates to find those collections made sufficiently distant from earlier ones to indicate a population established after long-distance dispersal, either by sea or through shipping. In the figures, the locations of the earlier collections are in bold. Collections made in the general vicinity shortly thereafter were mapped with indicative symbols, others with small circles. Coastline sections without data were then sketched in to complete the maps.

Oceanographic aspects

Oceanographic information for the seas around Australia was obtained from the literature and summarised in a map. For a detailed analysis of local currents I used retrieval reports from ballasted and empty drift bottles (Anon. 1968 a, b) and high density PVC cards (Marshallsay & Radok 1972). To assess the influence of wind on drifting objects, logbooks were inspected at the Bureau of Meteorology in Melbourne to obtain data on wind strength and direction during and after the drifter releases near Eclipse Island, Western Australia, and in Bass Strait.

Results

Species origins and propagule characteristics

Cakile edentula is indigenous to the Atlantic coast of North America, *Cakile maritima* and *Euphorbia paralias* to the shores of western Europe and the Mediterranean, and *Arctotheca populifolia* to those of southern Africa. All are strandline pioneers with buoyant propagules and play a role in foredune formation (Heyligers 1985; Fig. 1). The populations of *Arctotheca populifolia* from eastern Australia are noticeably different from those of western and southern Australia; they are less robust, have ovate leaves and

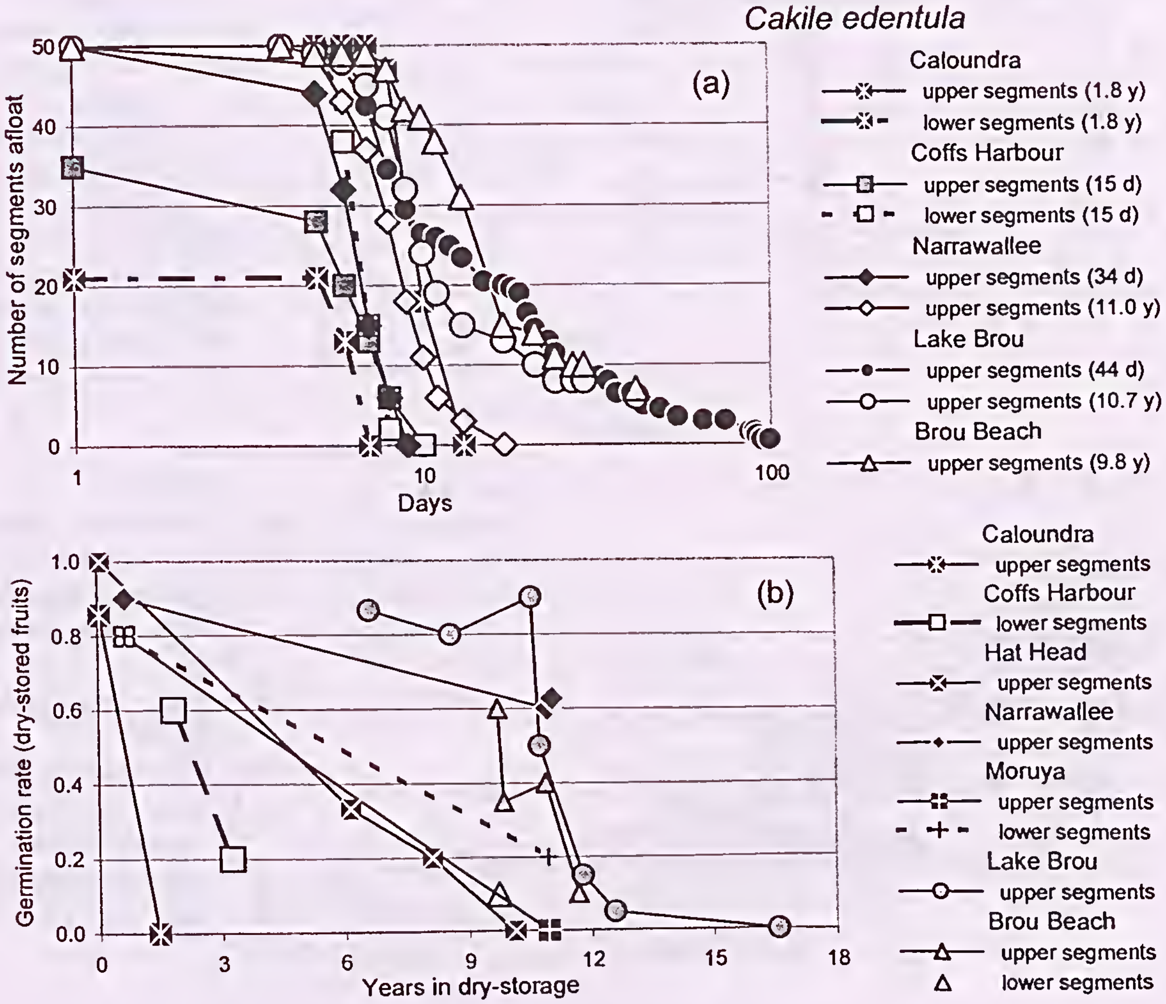

Fig. 2. Buoyancy (a) and viability (b) of dry-stored *Cakile edentula* fruit segments. Geographic names refer to sample locations. In the legend of (a) the time between collecting the fruits and starting the tests is given in parentheses. Where applicable, the number of segments afloat has been adjusted for removal of segments for viability testing. For viability testing pericarps were removed from the seeds. Data points for upper fruit segments have been connected by solid lines, those for lower segments by broken lines.

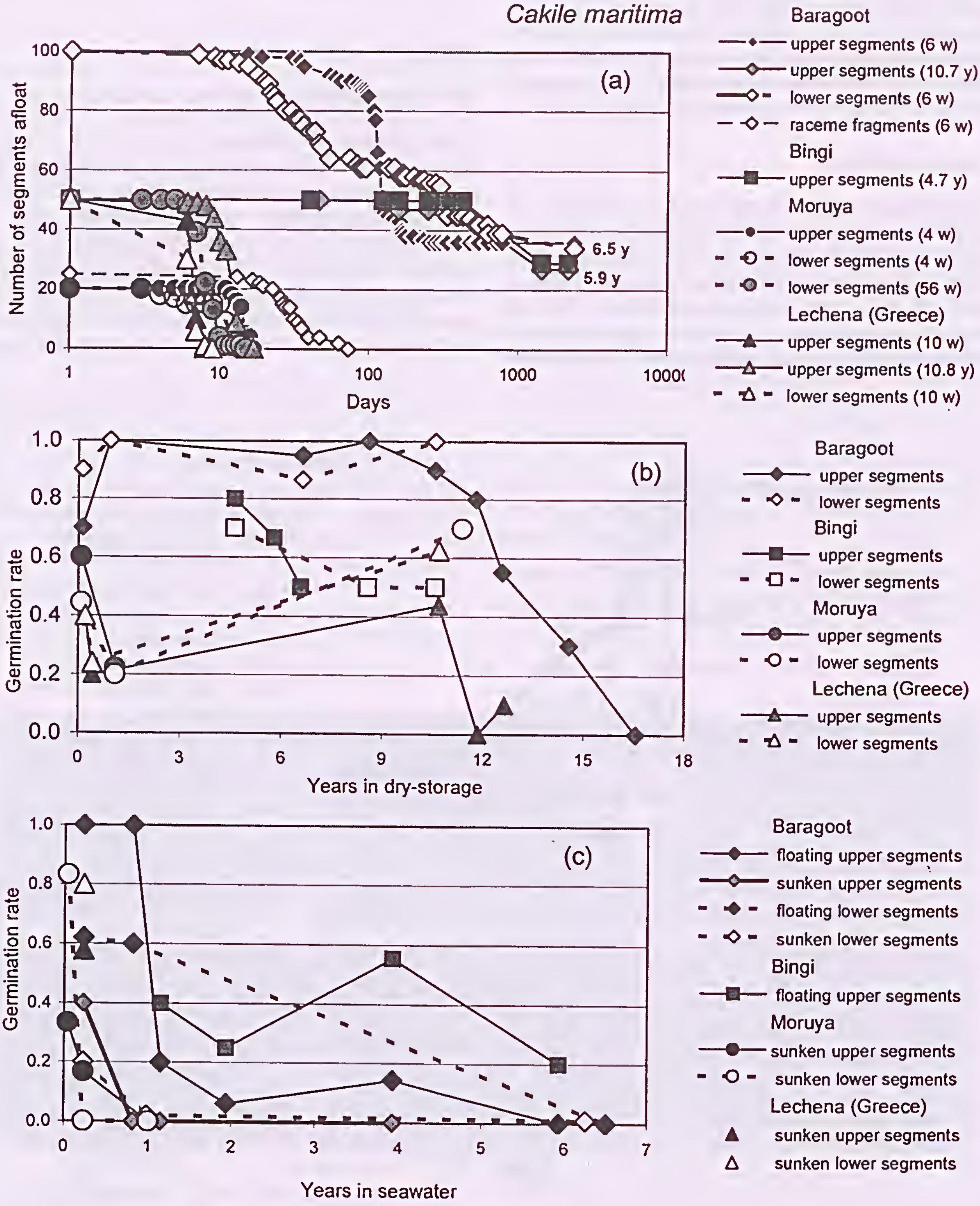

Fig. 3. Buoyancy (a) and viability of (b) dry-stored and (c) floating and sunken fruit segments of *Cakile maritima*. For comments see caption for Fig. 2.

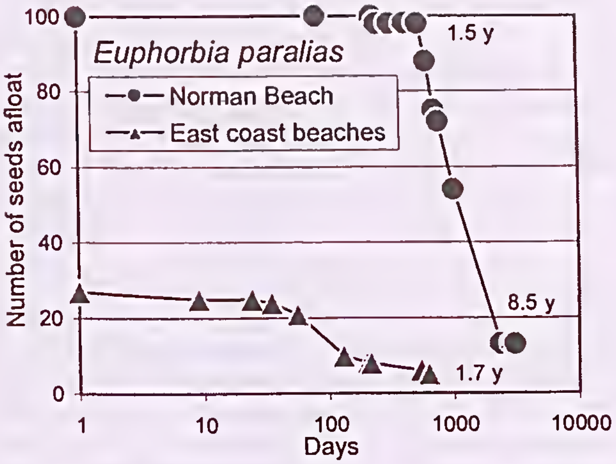

Fig. 4. Buoyancy of *Euphorbia paralias* seeds from Wilsons Promontory, Victoria.

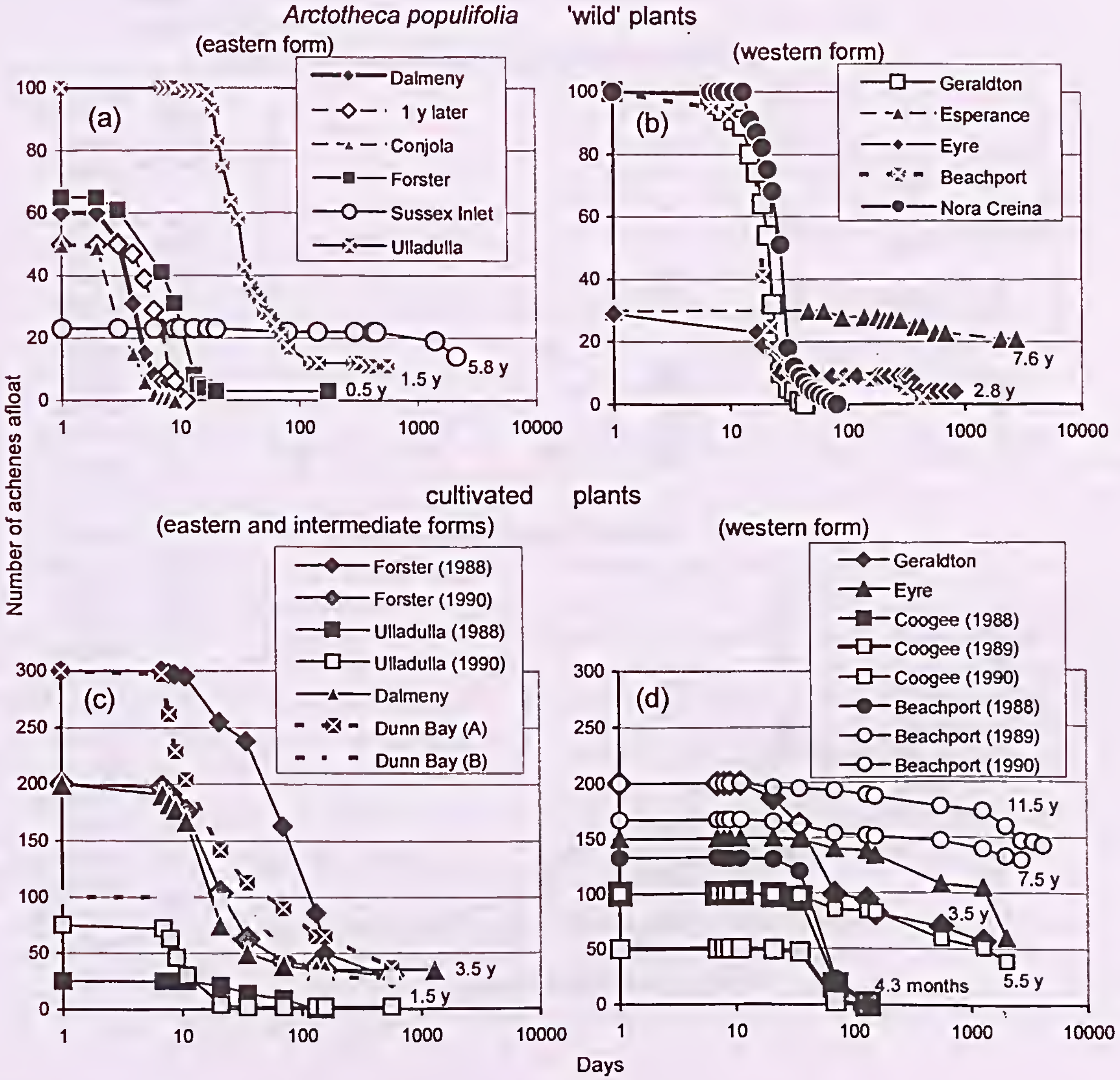

Fig. 5. Buoyancy of *Arctotheca populifolia* achenes: (a) from 'wild' plants of the eastern form, (b) from 'wild' plants of the western form, (c) from plants of eastern and intermediate forms grown from cuttings, and (d) from plants of the western form grown from cuttings. In the legend of (c) and (d) the dates in parentheses refer to the years of harvest.

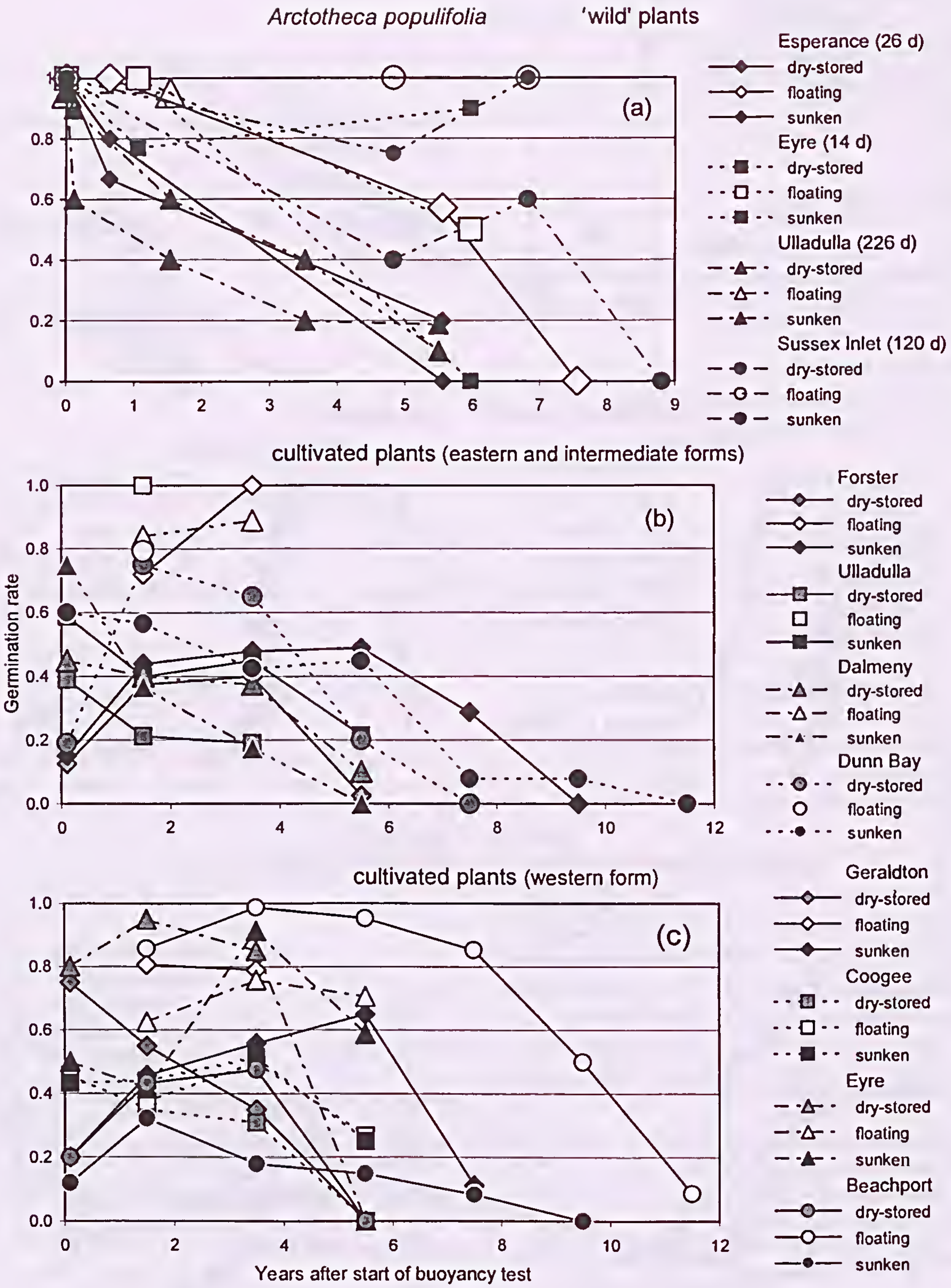

Fig. 6. Viability of *Arctotheca populifolia* achenes from plants of which at least some achenes stayed afloat for several years: (a) from 'wild' plants, (b) from plants of eastern and intermediate forms grown from cuttings, and (c) from plants of the western form grown from cuttings. In the legend of (a) number of days refers to time in storage before testing.

12–14 ray florets with well-developed ligules. The western form has leaves of an angular outline, sometimes with lobes along the transition to the petiole, and 12–19 ray florets with only short ligules. The forms have remained distinct, although some plants collected near Cape Naturaliste appeared to come close to the eastern form. The *Arctotheca populifolia* collections from South Africa in the Herbarium at Kew show a morphological variation that encompasses the forms found in Australia.

A *Cakile* fruit is c. 20 mm long and 6 mm wide, has a corky pericarp and consists of two, usually one-seeded, segments. On maturity the upper segment separates from the lower one, which remains attached to the plant. The fruit of *Euphorbia paralias* is a capsule containing three round seeds, which measure c. 3 mm across. The mature fruits open explosively, scattering the seeds up to 2 m from the plant (Heyligers 2002b). The pubescent achenes of *Arctotheca populifolia* are c. 5 mm long and 2.5 mm wide. The pubescence of the western form is consistently more luxurious than of the eastern form. The achenes drop onto the sand when the flowerheads have matured.

Propagule buoyancy and longevity

Most *Cakile edentula* and *Cakile maritima* fruit segments did not float longer than two weeks, a period marginally extended by prolonged dry storage (Figs. 2 and 3). These results are in agreement with observations of Guppy (1906), Rodman (1974) and Ignaciuk & Lee (1980). However, there were notable exceptions; from some *Cakile edentula* samples up to 25% of fruit segments stayed afloat for several months, while some of *Cakile maritima* did so for many years.

Dry fruit segments of *Cakile edentula* germinated after about 5 weeks, those of *Cakile maritima* after about 10 weeks. Exposure to seawater during one week before sowing at least halved germination times. Germination rates for *Cakile edentula* were initially better than 80% and declined slowly during storage with a few seeds still viable after 12 years. Germination rates for *Cakile maritima* were variable but some seeds remained viable for more than 15 years.

Viability of floating fruit segments of *Cakile edentula* declined rapidly and was lost after 6 weeks, with a noticeable exception of 6 seeds from a sample of 10 upper segments, which still germinated after 12 weeks. Once segments sank, seeds were no longer viable. Viability of *Cakile maritima* segments dropped sharply after a year or so, but a few seeds still germinated after segments had been afloat for 6 years. Seeds in sunken segments lost their viability rather quickly but some remained viable for 6 months. Loss of viability is likely due to seawater penetrating the fruit wall, because seeds removed from dry fruits and exposed to seawater lost their viability within a few days. The quicker deterioration of *Cakile edentula* fruits might be due to their thinner pericarp.

Most *Euphorbia paralias* seeds remained afloat for a year and a half, after which their number steadily declined for several years to stabilise at 13% (Fig. 4). After 8.5 years the experiment finished with the viability test of the last remaining seeds. Fresh seeds went through a dormancy period of about half a year after which the germination rate of dry and floating seeds was about 40%. Floating seeds maintained this rate for at least two years but none germinated after six years. The comparable figures for dry seeds were 13 and 16 years. No sunken seeds were viable.

Buoyancy periods of *Arctotheca populifolia* achenes proved highly variable (Fig. 5). Achenes from plants of the western form generally stayed afloat longer than those from the eastern form, a difference more marked in the tests with achenes from the cultivated plants. Some of the achenes collected at Sussex Inlet were still afloat after 5.8 years, some from Esperance after 7.6 years, while one in ten achenes from cuttings taken at Beachport were still afloat after 11.5 years.

Germination rates of fresh achenes varied, but usually 50% or more germinated (Fig. 6). There was no dormancy involved and while viability declined slowly during storage, some seeds remained viable for up to seven years. Germination rates of floating achenes were not uncommonly about 80% and remained high for up to eight years, while two of the 23 achenes from Beachport plants still germinated after floating for 11.5 years. Germination rates of sunken achenes were variable, but some were still viable after 7.5 years.

Currrent regimes

Currents around the southern and eastern coasts of Australia are shown in Fig. 7.

Data from drift card and drift bottle releases is given in Figures 9 to 13 with results summarised in Appendix 1. Relevant details are used in the analyses of individual plant dispersal histories.

The Leeuwin Current has its origin off north-west Australia and flows south between the Western Australian Current and the coast, narrowing and gathering speed during the process. Where it meets the Antarctic Circumpolar Current, it flows with speeds of up to 1.8 m sec^{-1} (or 150 km day^{-1}) along the upper slope of the continental shelf, but speeds closer inshore are at best 0.5 m sec^{-1}. The strength of the Leeuwin Current varies between seasons and from year to year (Cresswell 1991; Cresswell & Griffin 2004). In years of maximum flow, its influence is thought to extend to the west coast of Tasmania.

Currents off South Australia are primarily driven by the Antarctic Circumpolar Current. Already a century ago this was demonstrated by the stranding patterns of drift bottles released from vessels plying between eastern and western harbours (Russell 1894–1902; Lenehan 1904). In the Great Australian Bight, in response to the prevailing south-westerly winds, an anti-clockwise current is generated which flows most strongly along the eastern shore of the Bight (Herzfield & Tomczak 1999). In the rather isolated shallow waters of

Spencer Gulf and Gulf St Vincent currents are thought to circulate in a clockwise direction (Bullock 1975; Bye 1976). In south-eastern South Australia the easterly flow translates into a south-easterly longshore current. However, as winds turn more southerly during summer, it is displaced by the northerly flow of the Flinders Current (Bye 1983).

The Zeehan Current runs along the continental shelf edge off south-eastern South Australia, possibly originating from the outflow of high salinity water from the Gulfs and the Great Australian Bight (Cresswell 2000). It is a permanent but rather narrow c. 40 km wide current, which may reach speeds of 17.5 km day^{-1} and flows southward over the outer half of the shelf to the west coast of Tasmania. During the strong winter flow, satellite-tracked drifters were carried around the southern coast and up the east coast before coming under the influence of the East Australian Current (Fig. 7). During summer, when the Zeehan Current is weaker, drifters went only as far as the southern end of the island before being trapped by this current.

Bass Strait is a shallow coastal sea between Tasmania and the mainland. Although tidal currents dominate the circulation throughout the Strait, there is a residual mainly wind-driven current of highly variable speed and direction with easterly flows generally stronger than flows in other directions (Baines *et al.* 1991). During autumn and winter this current moves with an average speed of roughly 20 km day^{-1} (Fandry *et al.* 1985). In the northern half of the Strait it flows past East Gippsland and turns northward along the coast of New South Wales, while in the southern half it flows through the gap between Flinders Island and north-eastern Tasmania and then northward (Tomczak *et al.* 1984). During summer, when tidal flows dominate, the direction of the current off south-western Victoria reverses and reinforces the Flinders Current (Olsen & Shepherd 2006), but off south-eastern Victoria the flow is still predominantly eastward and changes to a northerly direction along the coast of New South Wales (Marshallsay & Radok 1972; Godfrey *et al.* 1980a).

The East Australian Current originates in the Coral Sea as the southward-flowing branch of the South Equatorial Current (Sokolov & Rintoul 2000; Spear & Steinberg 2001; Fig. 7). It flows most strongly along and beyond the continental shelf edge, although surface speeds, sometimes exceeding 1.5 m sec^{-1}, vary markedly in space and time. Currents nearer the coast are weaker and although generally correlated to the conditions further out to sea, on occasions reverse and flow

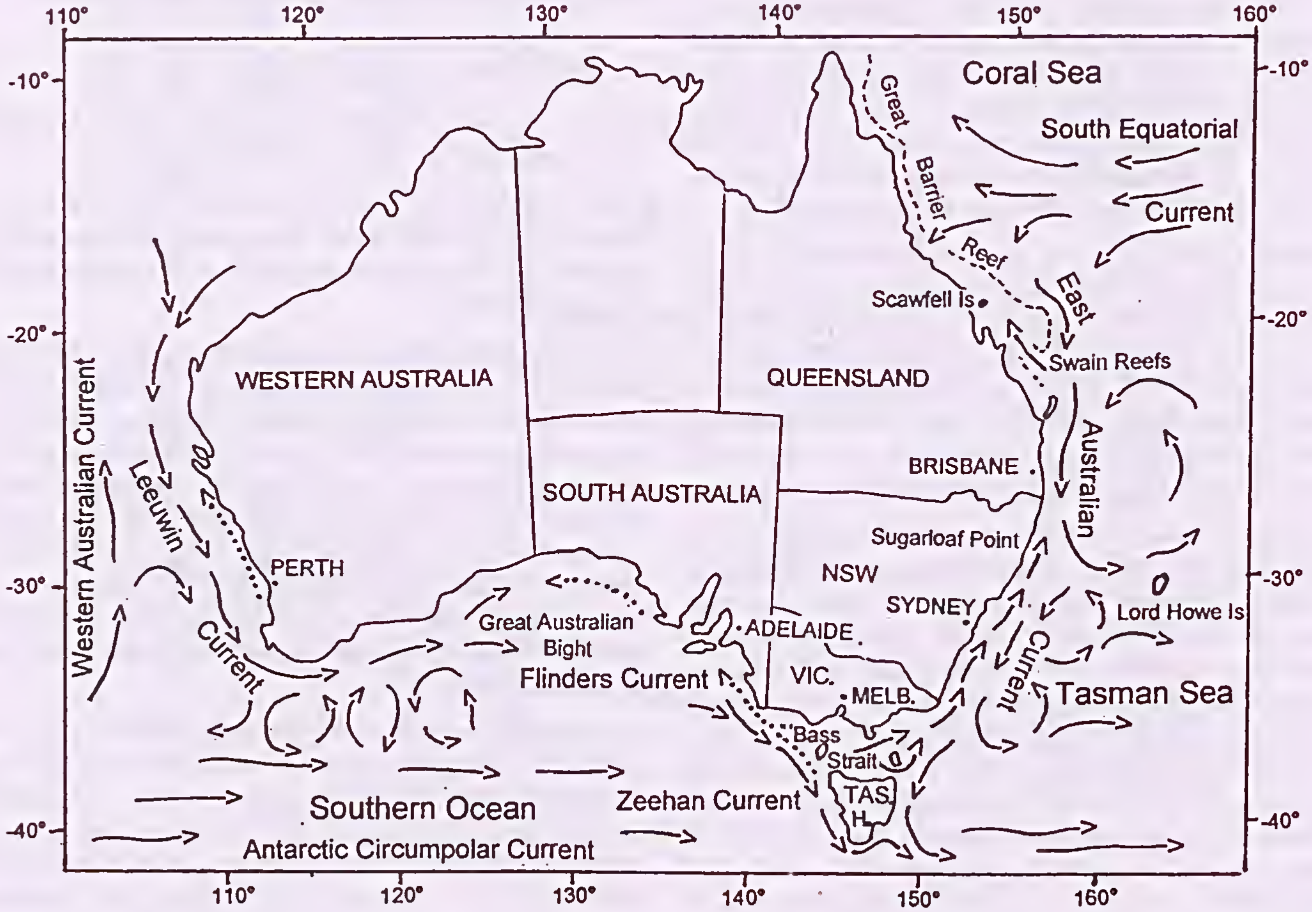

Fig. 7. Schematic of major currents operative in long-distance dispersal of strand- and foredune plants with buoyant propagules. Solid arrows represent permanent currents or currents mainly running during the winter half-year, stippled ones those running only during summer. The figure is based on papers referred to in Results: Current regimes.

northward (Cresswell *et al.* 1983). Off northern New South Wales, between Smoky Cape near South West Rocks and Sugarloaf Point near Seal Rocks, the East Australian Current veers away from the coast in a south-easterly direction (Godfrey *et al.* 1980b; Roughan & Middleton 2002).

Closer inshore, along the southern New South Wales coast, runs an intermittent and variable northerly counter-current, which originates from the easterly flow through Bass Strait. Near Sugarloaf Point it becomes to a greater or lesser degree entrained in the East Australian Current (Cresswell *et. al.* 1983). When the core of the East Australian Current is located far offshore, the northward flow is less impeded and a weak current of at best 0.4 m sec^{-1} continues along the coast north of Smoky Cape (Roughan & Middleton 2002). Near-shore currents off southern New South Wales, although variable in direction and strength (mostly < 0.5 m sec^{-1}), often have a marked onshore component (Huyer *et al.* 1988), presumably under the influence of south- to north-easterly winds.

The Great Barrier Reef occupies the continental shelf between the southern coast of Papua New Guinea and Fraser Island (Fig. 7). It consists of about 2500 individual reefs, varying in size from 0.1 to 100 km^2 (Wolanski 1994). A broken chain of outer reefs outlines the continental shelf edge. Where the South Equatorial Current meets the reef about 10% of the flow spreads onto the continental shelf, while the remainder divides into a northerly and southerly longshore current, the latter being the origin of the East Australian Current (Sokolov & Rintoul 2000; Brinkman *et al.* 2001). Two comprehensive investigations in the southern section of the reef (Griffin *et al.* 1987; Middleton *et al.* 1994) showed that the current regime is dominated by the tides, but also strongly influenced by local wind stress. Hence, due to the variable interactions between tides, wind and longer-term current phenomena, the resulting circulation is highly complex and subject to rapid change.

Also important for dispersal of drifting objects are the 'linear oceanographic features.' Expressed as 'slicks' on the surface, they are convergence zones of three-dimensional circulations resulting from interactions between water masses of different salinity, tidal currents, bottom topography and wind conditions (Kingsford 1990). Slicks vary in length from less than 100 m to many tens of kilometres. They are accumulation zones of plankton, drift algae and flotsam. Shorter slicks frequently occur in near-coastal situations, e.g. around headlands, islands, reefs or estuary entrances, and may facilitate the stranding of propagules. Longer ones, known as 'wind rows,' are aligned in the direction of the wind and their downwind speed is greater than that of their surroundings (Cresswell pers. comm.). Hence, windrows may not only concentrate drifting propagules, but also speed up their long-distance transport. Moreover, they can transfer drifting objects from one current system to another.

Dispersal of Cakile maritima

Cakile maritima was introduced into Western Australia towards the end of the nineteenth century (Fig. 8). The port of Fremantle is the likely point of entry, although another

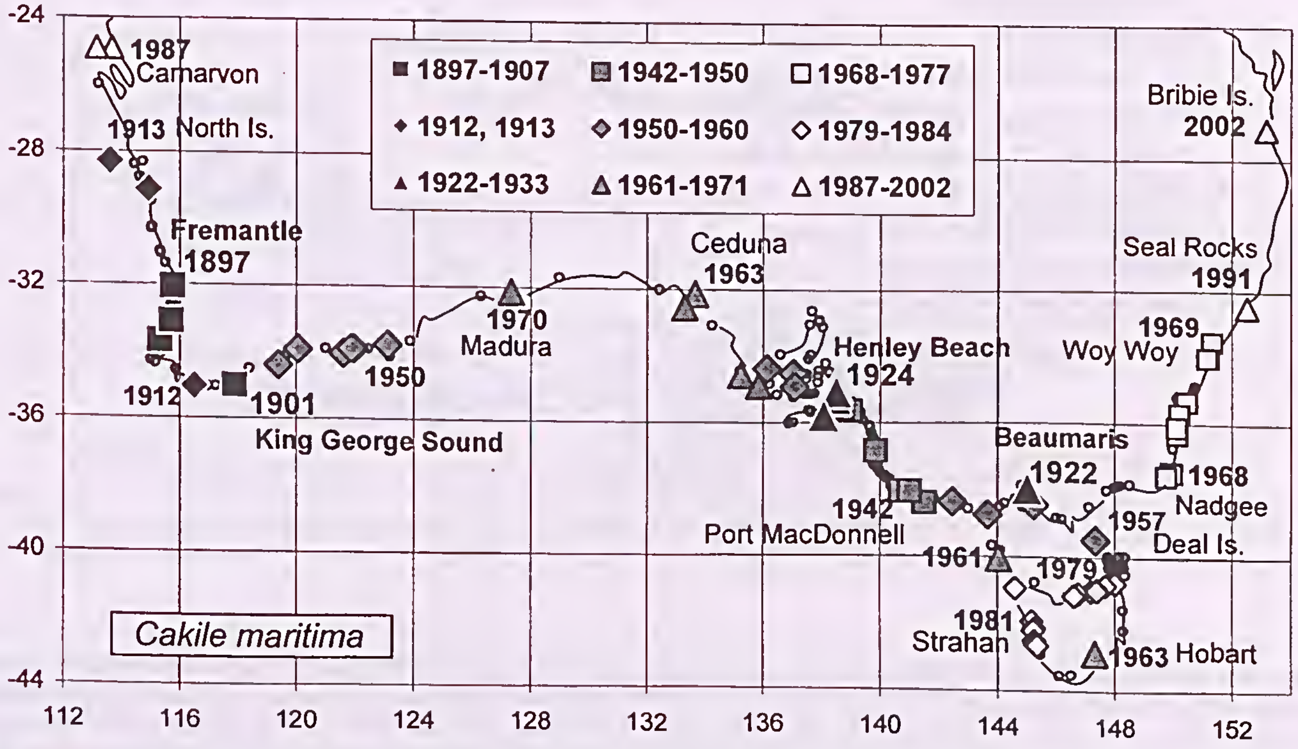

Fig. 8. Evidence for *Cakile maritima* dispersal, based on collection dates of 448 herbarium specimens. The progression of dates indicates a spread from early nodes near harbours in southern Australia to Carnarvon on the west coast and Bribie Island on the east coast.

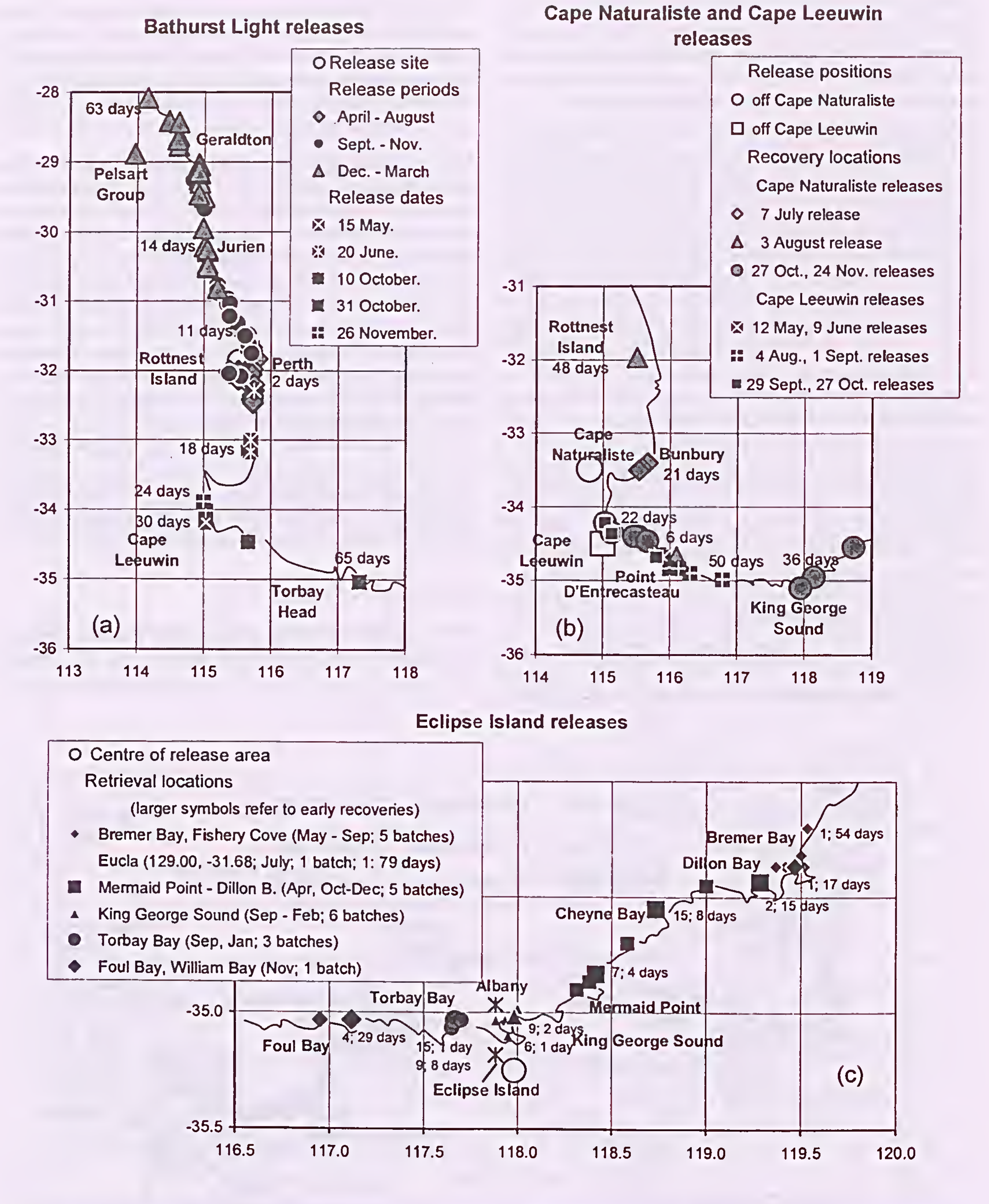

Fig. 9. Retrieval results of ballasted drift bottles, released in batches of 20, at four positions off the south-west coast of Western Australia between February 1956 and January 1957 (data from Anon. 1968b); (a) stranding locations of 136 bottles from 28 batches released 12.6 km north-west of Bathurst Light, north of Rottnest Island, (b) of 14 bottles from six batches released off Cape Naturaliste and 20 bottles from ten batches released off Cape Leeuwin, (c) of 113 bottles from 30 batches released off Eclipse Island. Locations have been grouped according to regions and dates or periods of release. Number of days refers to the time between release and recovery. The chart of (c) shows for some locations the number of bottles found and the time between release and the first bottle recovery.

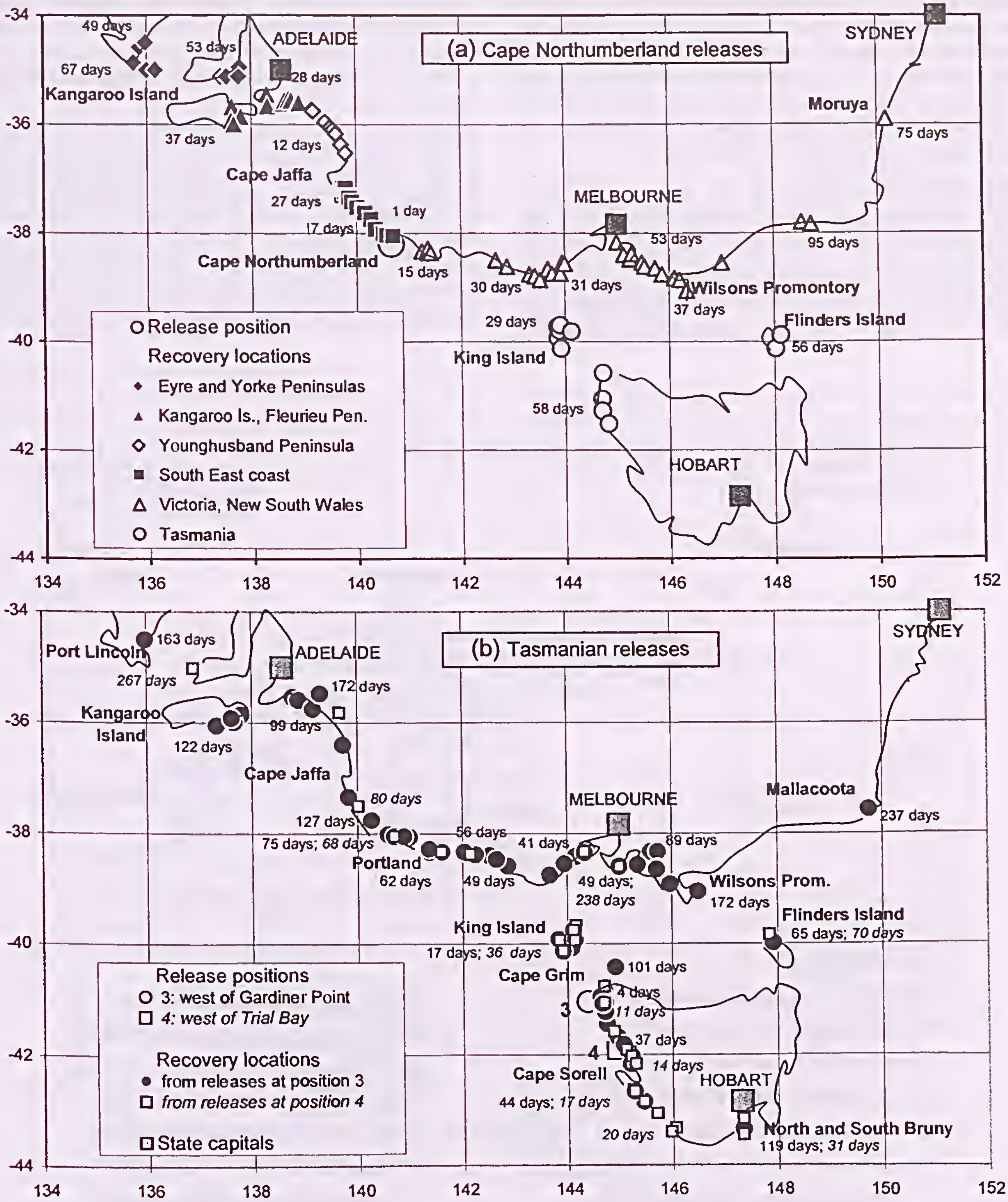

Fig. 10. Selected recoveries from batches of 50 ballasted bottles released near the western entrance to Bass Strait between September 1958 and May 1962 (data from Anon. 1968a). (a) Recoveries from 45 batches released about 14 km south of Cape Northumberland, (b) from 35 and 37 batches released at positions 3 and 4 off the north-western coast of Tasmania. Numbers of days indicate the shortest time between release and retrieval for particular locations. In (a) most strandings between the Fleurieu Peninsula and Wilsons Promontory have been left out. The strandings shown in (b) are from batches of which at least one bottle was found on a shore other than Tasmania's, together with strandings along the south-west coast from other batches. The retrieval of a bottle at Burleigh Heads, in south-eastern Queensland, after 307 days has not been mapped.

introduction at King George Sound is also a possibility. Within a decade or so it became widespread between these ports. Diels (1906) mentions that *Cakile maritima* was usually the first plant to be found on the loose sand of the flat shoreline. By 1913 it was also present at Dongara and on North Island of the Houtman Abrolhos group and by 1950 had spread to the Esperance — Israelite Bay coast and some of the islands of the Recherche Archipelago.

Drift bottles released during winter and spring north of Rottnest Island floated south and stranded not only along the west coast but also east of Cape Leeuwin as far as Torbay Bay (Fig. 9). A similar drift pattern for this time of year was also evident from releases off Cape Naturaliste and Cape Leeuwin, with strandings as far west as Cheyne Bay. Bottles were often adrift less than a month, short enough for some *Cakile maritima* fruits to remain afloat. Hence, it would appear that in addition to local dispersal processes linked to tidal and inshore currents, the Leeuwin Current provided an efficient vehicle for dispersal in south-western Western Australia.

In 1922 *Cakile maritima* was collected at Beaumaris along the shore of Port Phillip Bay, Victoria, and two years later also at Henley Beach near Adelaide, locations again close to busy harbours (Fig. 8). Whether these were new introductions from overseas or originated from populations in Western Australia cannot be determined, but I think it unlikely that propagules floated across from Western Australia. Apparently, the plants at Beaumaris failed to establish a viable

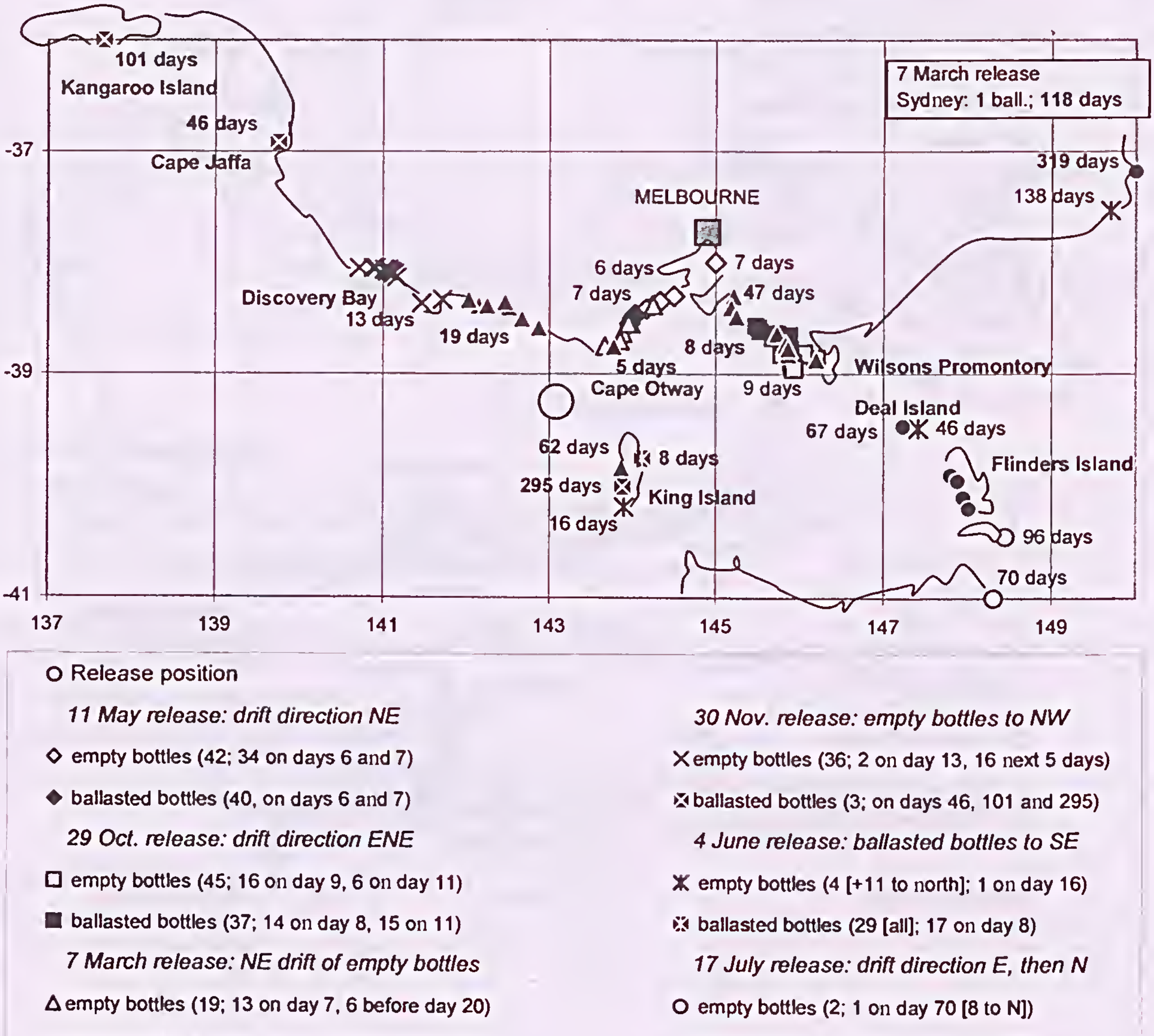
101 days
Kangaroo Island
46 days
Cape Jaffa
-37
7 March release
Sydney: 1 ball.; 118 days
319 days
138 days
MELBOURNE
6 days
7 days
7 days
47 days
Discovery Bay
13 days
19 days
8 days
5 days
Cape Otway
9 days
Wilsons Promontory
-39
Deal Island
67 days
46 days
62 days
8 days
295 days
King Island
16 days
Flinders Island
96 days
70 days
-41
137
139
141
143
145
147
149
O Release position
11 May release: drift direction NE
◇ empty bottles (42; 34 on days 6 and 7)
◆ ballasted bottles (40, on days 6 and 7)
29 Oct. release: drift direction ENE
☐ empty bottles (45; 16 on day 9, 6 on day 11)
■ ballasted bottles (37; 14 on day 8, 15 on 11)
7 March release: NE drift of empty bottles
△ empty bottles (19; 13 on day 7, 6 before day 20)
▲ ballasted (43; 1 on day 5, most within 2 months)
30 Nov. release: empty bottles to NW
✕ empty bottles (36; 2 on day 13, 16 next 5 days)
☒ ballasted bottles (3; on days 46, 101 and 295)
4 June release: ballasted bottles to SE
✱ empty bottles (4 [+11 to north]; 1 on day 16)
☒ ballasted bottles (29 [all]; 17 on day 8)
17 July release: drift direction E, then N
○ empty bottles (2; 1 on day 70 [8 to N])
● ballasted bottles (11 [all]; 4 on day 67)

Fig. 11. Results of six releases off Cape Otway where batches of 50 non-ballasted ('empty') and 50 ballasted bottles were released at about monthly intervals in 1960 (data from Anon. 1968a). Number of days usually refers to the time between release and the first reported stranding(s), but for widely spread strandings, to later dates as well. Numbers of days in bold refer to ballasted bottles. Although large numbers of bottles beached on King Island, only the stranding site of one bottle per batch has been mapped.

population, as there were no further collections from around the Bay for another 30 years, but *Cakile maritima* became well-established along the beaches of Gulf St Vincent. In summer, when winds are mainly south-easterly, drift cards released at the entrance of the Gulf stranded at the western side of the Gulf, while those released during winter, under influence of south-westerlies, stranded on the eastern shores (Petrusevics 1990, 1991). It is likely that the predominance of the southerly winds kept fruits confined to the Gulf for many years as it was not until the 1940s that *Cakile maritima* was also collected at other locations in south-eastern South Australia. The first of those collections was made at Port MacDonnell, an indication that the fruits had come under the influence of the south-easterly longshore current once they had 'escaped' from the Gulf.

In 1950 *Cakile maritima* was collected at Cowes on Phillip Island, in 1953 at Apollo Bay on the Otway coast, and in 1957 on Deal Island, indicating that the fruit segments, like drift bottles released near Cape Northumberland and Cape Otway (Figs. 10 and 11), were spreading through the northern half of Bass Strait. It was not until the mid 1960s that *Cakile maritima* was found on King Island and much later before it was collected on the west and north coast of Tasmania. The fruits colonising King Island and the west coast are likely to have been carried from the mainland by the Zeehan Current. Drift bottles released near Cape Northumberland were found in north-west Tasmania after 58 days (Fig. 10a), a period sufficiently short for many *Cakile* fruit segments to stay afloat. *Cakile maritima* became widespread along the north coast, a reflection of efficient local distribution by the predominantly tidal currents that dominate the southern waters of Bass Strait as demonstrated by the drift card study of Marshallsay & Radok (1972; Fig. 12). An isolated find near Hobart in 1963, like four decades earlier in Phillip Bay, appeared to have failed to lead to further colonisation of the east coast.

Collections made in 1968 and 1969 were the first indication that *Cakile maritima* occurred in far East Gippsland and New South Wales. During the 1970s it was collected 14 times along the NSW South Coast, twice as often as *Cakile edentula*.

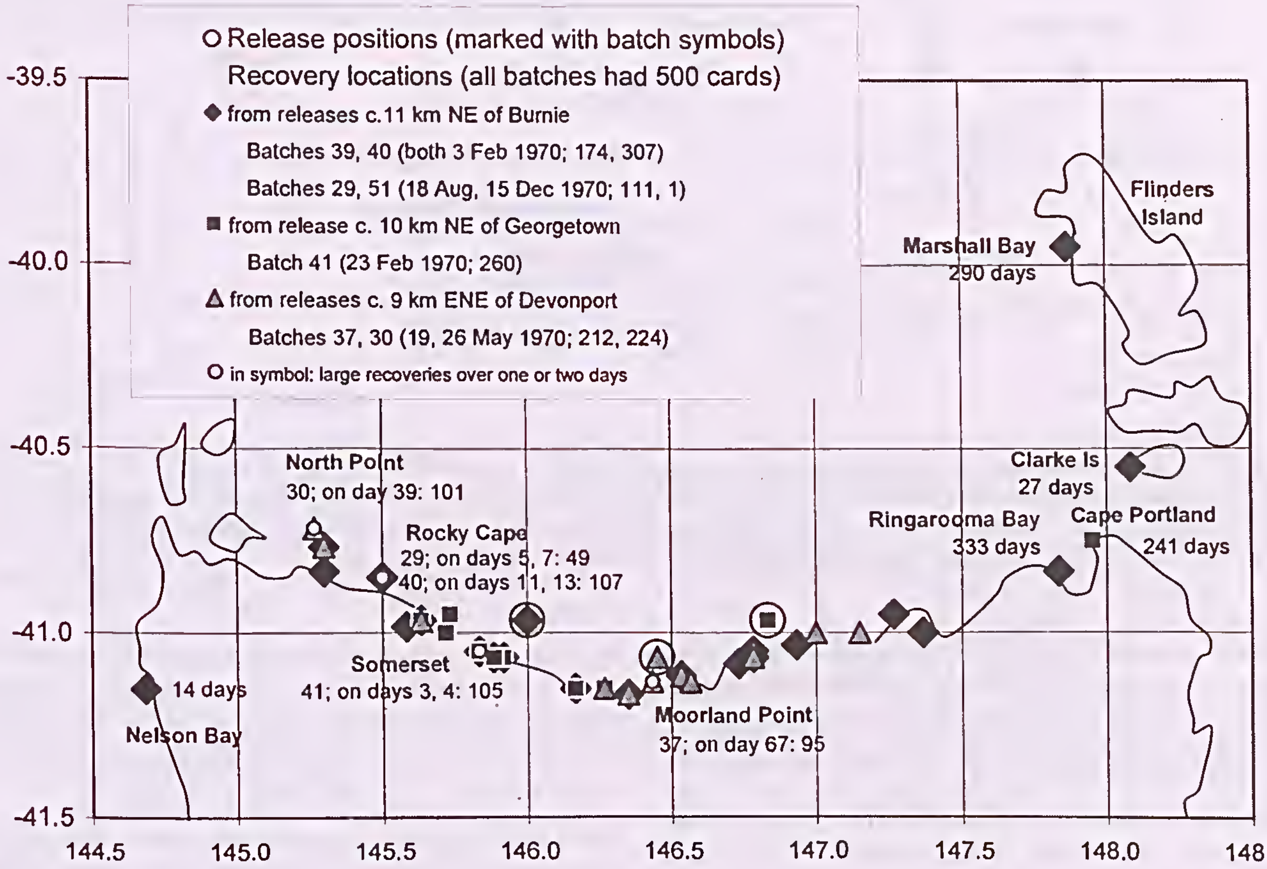
○ Release positions (marked with batch symbols)
Recovery locations (all batches had 500 cards)
◆ from releases c.11 km NE of Burnie
Batches 39, 40 (both 3 Feb 1970; 174, 307)
Batches 29, 51 (18 Aug, 15 Dec 1970; 111, 1)
■ from release c. 10 km NE of Georgetown
Batch 41 (23 Feb 1970; 260)
△ from releases c. 9 km ENE of Devonport
Batches 37, 30 (19, 26 May 1970; 212, 224)
○ in symbol: large recoveries over one or two days
-39.5
-40.0
-40.5
-41.0
-41.5
144.5
145.0
145.5
146.0
146.5
147.0
147.5
148.0
148.5
Flinders Island
Marshall Bay
290 days
Clarke Is
27 days
Ringarooma Bay
333 days
Cape Portland
241 days
North Point
30; on day 39: 101
Rocky Cape
29; on days 5, 7: 49
40; on days 11, 13: 107
Somerset
41; on days 3, 4: 105
14 days
Nelson Bay
Moorland Point
37; on day 67: 95

Fig. 12. Retrieval locations of drift cards released on seven occasions during 1970 in batches of 500 off the north coast of Tasmania (data from Marshallsay & Radok 1972). The legend gives release dates and total numbers of cards retrieved. Batch number(s) and retrieval data have been added to the names of early and some outlying stranding locations. If strandings happened over a long period, only the data for the first two are given. Three recoveries outside Tasmania have not been mapped.

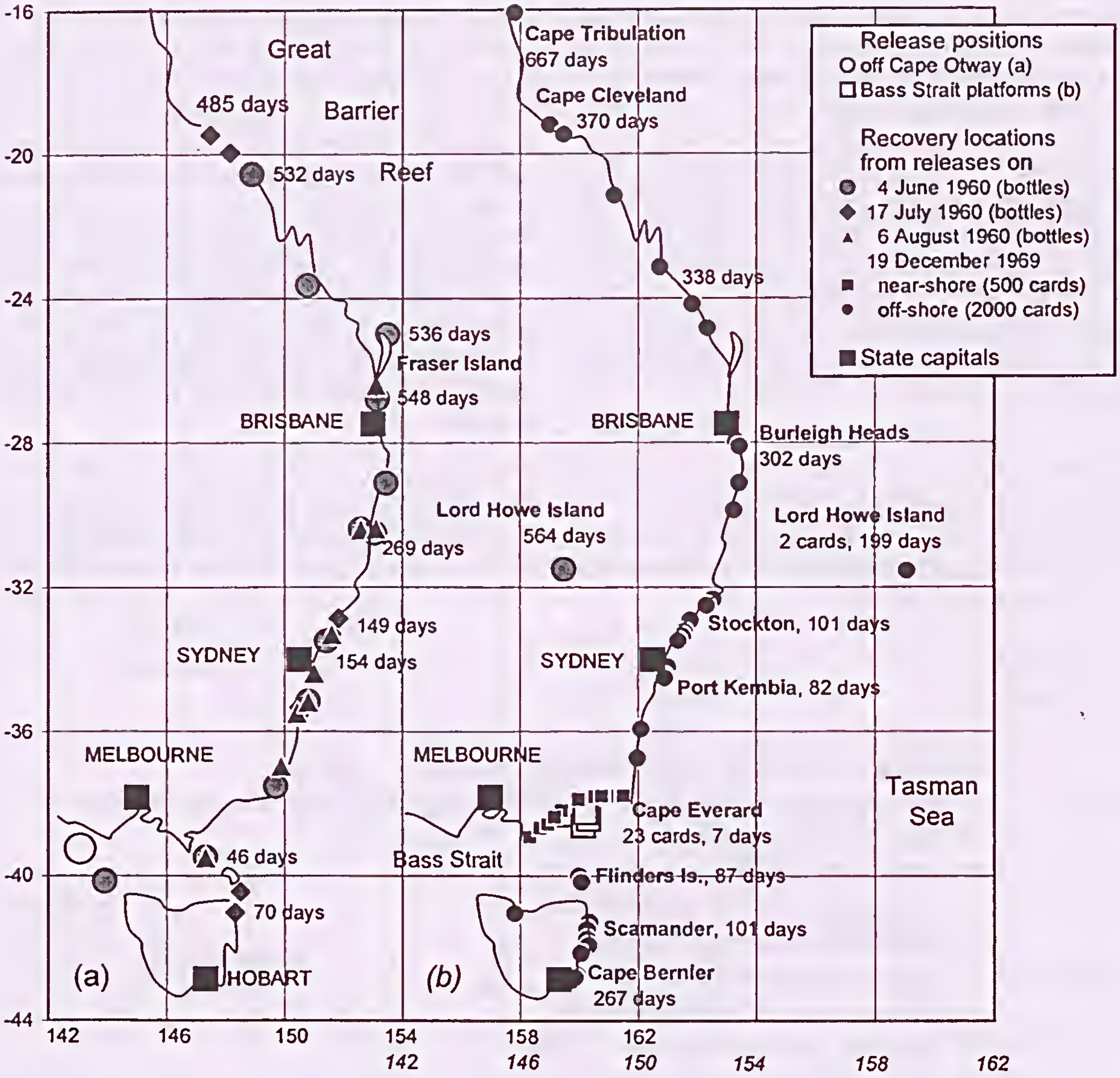

Fig. 13. East coast retrieval locations of 150 empty bottles released about 55 km south-west of Cape Otway during the winter months of 1960 (a), compared with those of the 2500 drift cards released on 19 December 1969 from oil and gas platforms at the north-eastern entrance to Bass Strait *(b)*. Numbers of days indicate time between release and retrieval. Data for (a) from Anon. (1968a), for *(b)* from Marshallsay & Radok (1972); the maps have been partly overlaid for easier comparison.

Could this mean that *Cakile maritima* had been overlooked due to its resemblance to *Cakile edentula*? Probably not. If that had been the case, it should have appeared among the 13 *Cakile edentula* collections made between 1955 and 1968. Moreover, in view of the fact that it was only in 1957 that *Cakile maritima* was collected on Deal Island, its appearance at the south-eastern corner of the mainland 11 years later seems to be 'right on target.' It is noteworthy that most of the long sandy shore of Gippsland was bypassed, indicating a propagule origin west of Wilsons Promontory in accordance with the outcomes of drifter experiments (Figs. 11 and 13). The collection at Woy Woy could indicate that fruit segments had been carried northward along the coast and, if the seeds that arrived at Woy Woy had been a few of a large propagule wash-out, the widespread occurrence of the species along the South Coast soon afterwards could have originated from the same event.

There is a large gap in time before *Cakile maritima* was collected near Forster on the NSW North Coast in 1991 and, in 2002, on Bribie Island in southeastern Queensland. Apparently, occurrences remain sporadic but further colonisation could be expected in view of the ongoing spread of *Cakile edentula* to be discussed later.

Dispersal of Euphorbia paralias

Euphorbia paralias, first found near Albany in 1927, spread eastward from King George Sound and in 1950 was collected at Esperance and in the Recherche Archipelago. In the following decades it spread further east along the western shore of the Great Australian Bight (Fig. 14). *Euphorbia paralias* was not found west of King George Sound until a 1986 survey revealed some localised occurrences between the Sound and Point D'Entrecasteaux (Heyligers 1989a). A few years later large populations were found on the west coast on the shores of Geographe Bay (Heyligers 1989a) and Garden Island (Keighery & Dodd 1997).

The results from drift bottle releases near Eclipse Island (Fig. 9c) show drift into King George Sound during spring and summer, the Bremer Bay area as the nearest long-distance destination during winter, strandings between these locations to be common in the transition periods between these seasons, and only very infrequent strandings west of Torbay Bay. It would appear that during summer, with the prevailing southerly winds, flotsam could get 'locked up' in the Sound, which then may function as a source for dispersal in an easterly direction. Its shape would impede drift in other directions, especially during periods of a strongly flowing Leeuwin Current. This may explain why 60 years elapsed before *Euphorbia paralias* was found west of King George Sound. However, it is also possible that dispersal to these areas and further north along the west coast may have been assisted by human agencies, such as transport on fishing vessels (Keighery & Dodd 1997) or by recreational vehicles (pers. obs.)

In 1934 *Euphorbia paralias* was found near Port Victoria on the east coast of the Spencer Gulf (Fig. 14). As this was only a few years after being collected at Albany, its occurrence close to a harbour points again to being introduced through shipping. Initially, *Euphorbia paralias* became common along the eastern shore of the Gulf before spreading to the western shore. However, seeds remained 'locked up' in the Gulf for several decades, as it was not before 1958 that the first collection was made outside the Gulf, on the western extremity of Kangaroo Island.

Ten years later, at Normanville, *Euphorbia paralias* was collected on the eastern shore of Gulf St Vincent close to the entrance and open to the strait between Yorke Peninsula and Kangaroo Island. An easterly current runs through the strait; so it is likely that the colonising seeds came from the population in Spencer Gulf. The species has become very common in the Normanville area, has gradually extended its range northward and is now widespread along the east coast of the Gulf.

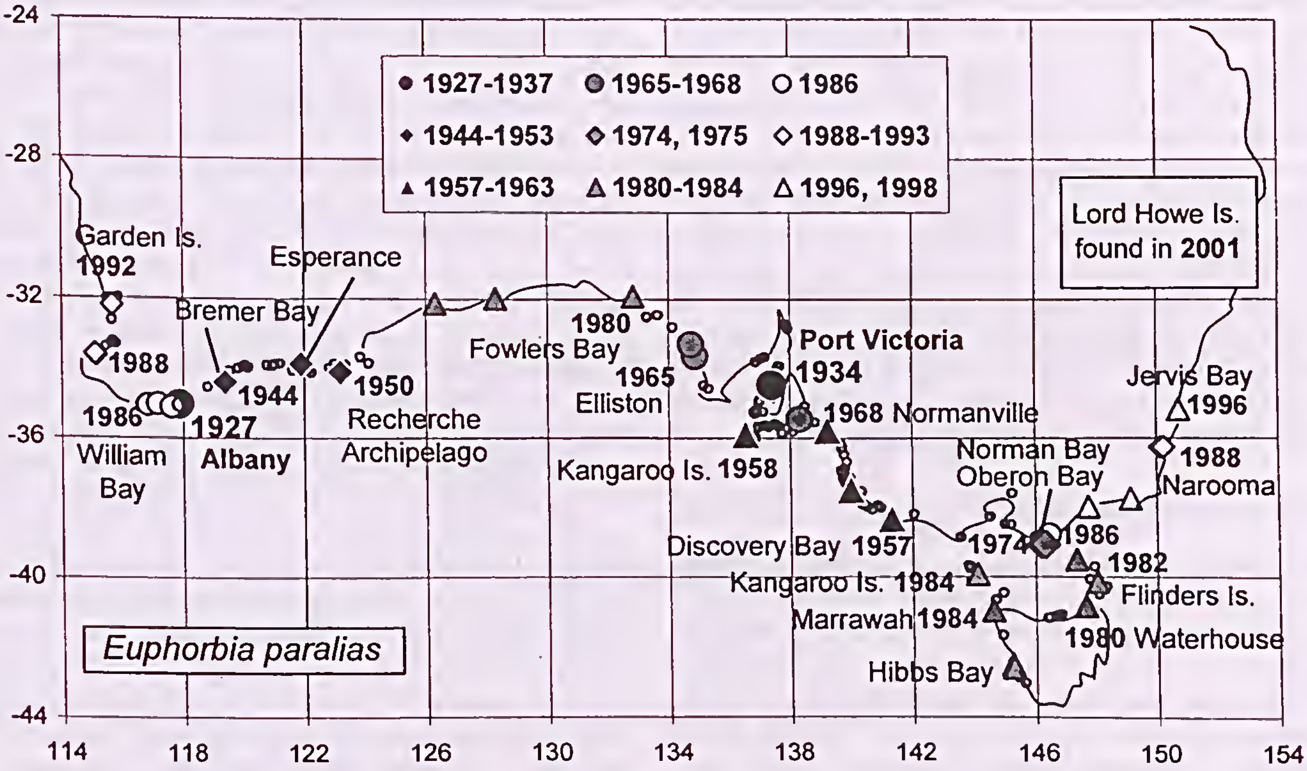

Fig. 14. Evidence for *Euphorbia paralias* dispersal, based on collection dates of 242 herbarium specimens. The progression of dates indicates a spread from early foci near Albany in King George Sound and Port Victoria on the east coast of the Spencer Gulf to the Perth region, the NSW South Coast and Lord Howe Island.

In the same period *Euphorbia paralias* also spread to Bass Strait and in the mid-1970s was found twice along bays in the south-west corner of Wilsons Promontory. The colonising seeds could have come from Western Australia as well as from the South Australian Gulfs. Apparently, this population was the result of a colonisation by seeds that had floated more than halfway through Bass Strait before making landfall as it was only in the 1980s that *Euphorbia paralias* made its appearance on the intervening coast of Victoria, on King Island and along the Tasmanian west coast, on islands in eastern Bass Strait, and on the adjacent coast of Tasmania.

In 1984, *Euphorbia paralias* was collected at three locations along the west coast of Tasmania, at one of which only one plant was seen. In 2001 a detailed survey found this species to be widespread and at many sites with populations of hundreds, if not thousands, of plants (Hilton pers. comm.). Once seeds transported by the Zeehan Current had established local populations, that rapid local dispersal was almost guaranteed as indicated by the results from drift bottle releases off the west coast (Fig. 10b). There are no *Euphorbia paralias* collections from Tasmania's east coast and in 2001 this species was only found at one of 18 locations searched in the south-east (Hilton pers. comm.). Hilton's survey also found a couple of occurrences on the central east coast, where I had seen no *Euphorbia paralias* in 1993. It is possible that the seeds were carried up the east coast during the strong winter flows of the Zeehan Current.

Euphorbia paralias turned up along the NSW South Coast in the late 1980s and at Cape Conran in East Gippsland in 1993. Soon thereafter it was seen at several other sites in the eastern part of East Gippsland, which formed foci for further local spread. In New South Wales it now occurs as far north as Jervis Bay (Heyligers 2002a, b). In 2000 a large population was found in Nadgee Nature Reserve, close to the Victorian border; its size was such that this area could have been colonised earlier than the beach south of Narooma. As, again, there was an initial bypassing of East Gippsland, the source of the seeds would have been somewhere west of Wilsons Promontory. Likewise, one may assume that the seeds for the recent colonisation at Lord Howe Island also came from this source. Strandings of drifters released in Bass Strait certainly support this assumption (Fig. 13).

Dispersal of Arctotheca populifolia

Between 1930 and 1936 *Arctotheca populifolia* was collected seven times in the far south-western corner of Western Australia, which indicates that it must have arrived several years, if not a decade or so, earlier (Fig. 15). Hence, it is difficult to be sure about where and how long ago it was introduced. Carried by the Leeuwin Current, achenes spread eastward, reaching Esperance by 1950 and the western shore of the Great Australian Bight by 1962. During the 1970s *Arctotheca populifolia* established on the tip of the Eyre Peninsula; by the mid-1980s it had colonised beaches and sand-drifts at the Head of the Bight and in the South-East of South Australia, while in 2001 it was found near Nelson along Discovery Bay (N. Walsh pers. comm.). In the 1970s the nearest source of *Arctotheca populifolia* fruits was the southern coast of Western Australia and one may assume that the fruits that stranded on the Eyre Peninsula and in south-eastern South Australia had drifted across from Western Australia. The charts of Russell (1894–1902) and Lenehan (1904) show these coastal sections prone to receiving ocean flotsam from the Antarctic Circumpolar Current (Fig. 7). Several bottles stranded in the Head of the Bight and, given that the occurrences of *Arctotheca populifolia* there are still isolated, it is possible the colonisation of that area has also been through achenes originating in Western Australia.

At present the western form of *Arctotheca populifolia* is poised at the north-western entrance to Bass Strait for further expansion and the question is: where will it appear first? If the evidence of the spread of *Cakile maritima* and *Euphorbia paralias* is an indication, *Arctotheca populifolia* could appear along the coast of Victoria as far west as Wilsons Promontory, before spreading to King Island and, later, to islands at the eastern side of Bass Strait and to the west and north coasts of Tasmania.

Almost contemporaneous with the early collections in Western Australia, three *Arctotheca populifolia* collections were made on the east coast near Newcastle, the first one near Mungo Brush in Myall Lakes National Park. These early locations bear the hallmark of an original introduction through shipping from South Africa. The spread of the eastern form has been slow. In 1953 it was collected near Port Macquarie and field work has shown that it still does not occur beyond South West Rocks, about 60 km to the north (Clarke 1989 a, b; pers. obs.). Along the NSW South Coast *Arctotheca populifolia* was first collected at Jervis Bay in 1955 and has become fairly widespread, albeit in low numbers, as far as Mallacoota (Clarke 1989a, b; Heyligers 1989b, 1991). In 1990 it was also found on the east coast of Flinders Island, but has not yet been reported from Tasmania. It took *Cakile maritima* less than 30 years to achieve a distribution along the east coast of the mainland that virtually matches that of *Arctotheca populifolia*. Why was the spread of *Arctotheca populifolia* along the east coast apparently slow and erratic? As the fruits of these two species have fairly similar buoyancy characteristics, it is probably due to its prolific propagule production, that *Cakile maritima* has spread more rapidly than *Arctotheca populifolia*. Also, when flowerheads of *Arctotheca populifolia* mature, they bend down to the surface within the confines and along the perimeter of the procumbent parent plant, where they are prone to be covered by wind-blown sand, thus kept out of circulation until exposed by erosion.

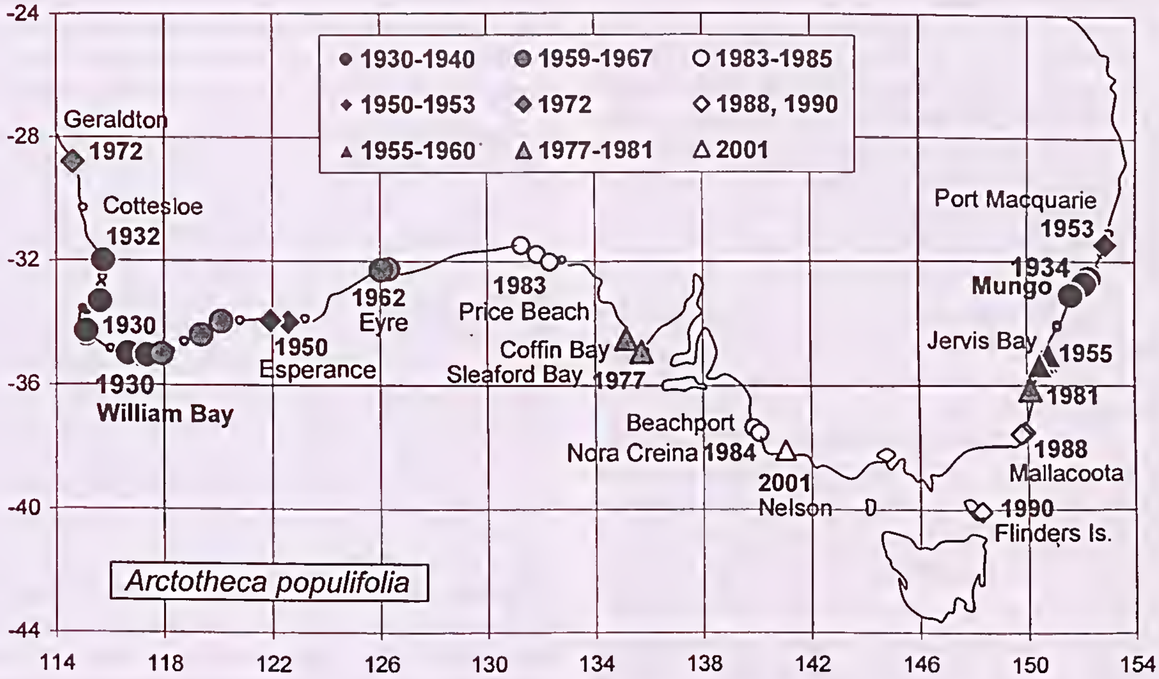

Fig. 15. Evidence for *Arctotheca populifolia* dispersal, based on collection dates of 73 herbarium specimens of the western form and 40 of the eastern form. The western form has spread from south-western West Australia along the west coast to Geraldton and along the southern coast to Nelson in western Victoria. The eastern form has spread predominantly southwards from the Newcastle area and has reached Flinders Island.

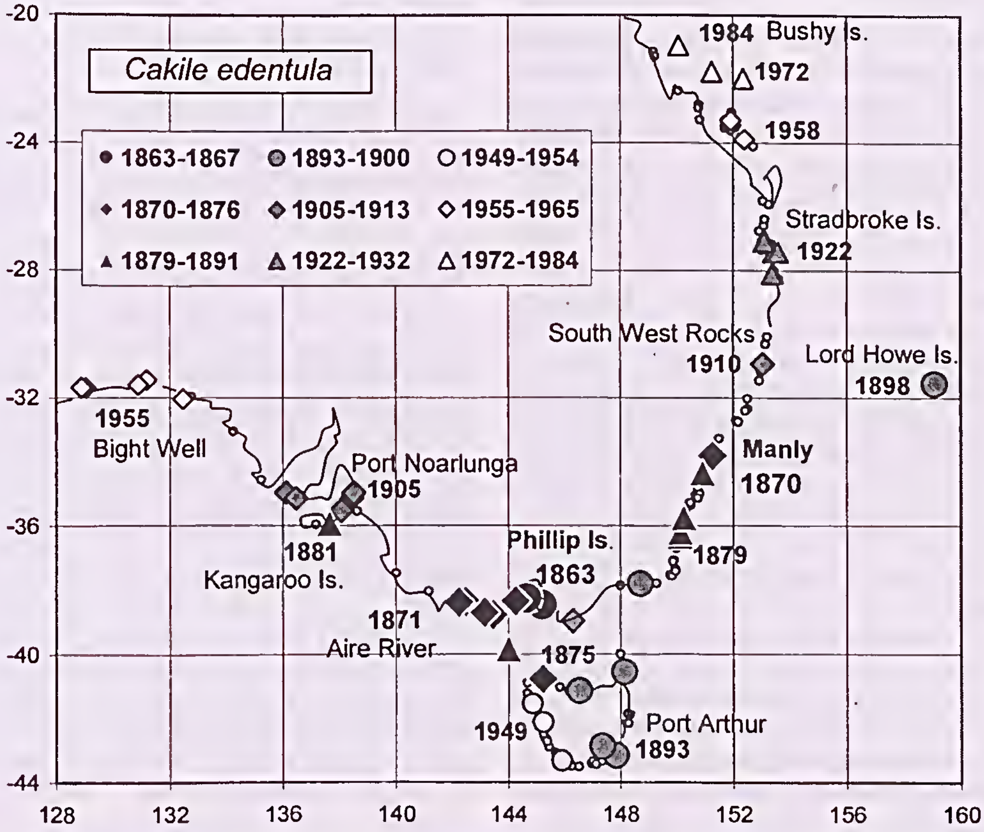

Fig. 16. Evidence for *Cakile edentula* dispersal, based on collection dates of 276 herbarium specimens. The progression of dates indicates a spread from the northern shores of Bass Strait to the Head of the Bight, southern Tasmania, Lord Howe Island, and Bushy Island of the Great Barrier Reef.

Dispersal of Cakile edentula

Cakile edentula probably arrived in Australia in ballast or gear of American sealing vessels from the New England region in the early decades of the nineteenth century (Rodman 1974). There are no collections from this period, but the situation changed during the latter half of the century. *Cakile edentula* became widespread along the shores of Bass Strait, Kangaroo Island and the southern coast of New South Wales (Fig. 16). The 1870 collection date from Manly, near Sydney, and the 1893 date from Port Arthur suggest that the occurrences there originated from secondary introductions. Be that as it may, the widespread occurrences in Bass Strait would have provided an important source for dispersal, as demonstrated by the strandings of cards and bottles (Fig. 13). In the twentieth century *Cakile edentula* spread westward as far as Eucla, southward along the west coast of Tasmania and northward along the east coast to central Queensland and several islands of the southern section of the Great Barrier Reef.

In 1922 *Cakile edentula* was collected on Stradbroke Island, south-east of Brisbane in Moreton Bay. The label of a collection made a few years later mentions that it was 'abundant on sand dunes near the sea.' In 1930 it was also collected on Bribie Island, north-east of Brisbane. The appearance of this species in the Moreton Bay region could have been due to shipping, but arrival through long-distance drifting is also a possibility.

During the 1930s *Cakile edentula* became widespread along the coast and adjacent islands of south-eastern Queensland. Early collection dates indicate a steady northward progression. The arrival of *Cakile edentula* in the southern section of the Great Barrier Reef is documented by a 1958 collection from Heron Island and soon afterwards it was also found on several other islands of the Capricorn and Bunker Groups. The northerly spread continued and in 1972 *Cakile edentula* had reached Gannet Cay, a small island of the Swain Reefs, while in 1984 and 1989 it was collected on Bushy Island and in 1986 on Scawfell Island (Batianoff 1995), both about 300 km north-west of the Capricorn Group and about 50 km distant from each other. The spread along the mainland coast went on apace; in 1993 *Cakile edentula* was collected twice near Mackay, at about the same latitude as Scawfell Island.

The gradual spread of *Cakile edentula* in a north-westerly direction is in agreement with results obtained with surface drifters released in the vicinity of the Capricorn Group, which showed that on occasions drifters stranded near or past Mackay. Later, hydrographic research confirmed that, after accounting for tidal effects and other periodic events, the remaining flow is to the north-west due to the predominance of south-easterly winds and inflow from an eddy over a bench in the continental slope (Marion Plateau) (Griffin *et al.* 1987). Is it likely that the spread of *Cakile edentula* will continue in that direction? The current regime in the central section of the Reef differs from that of the southern section. It is influenced to a greater degree by the East Australian Current due to fewer reefs in the Outer Reef and consequently, has a larger southerly component (Wolanski 1994). This could prevent, or at least delay, further expansion of *Cakile edentula*.

Repeated investigations of the flora of several Barrier Reef islands have shown that occurrences are often ephemeral (Chaloupka & Domm 1985; Flood & Heatwole 1986). By the same token, *Cakile edentula* occurrences on the mainland are often scattered and temporary and the species has virtually disappeared from the Bass Strait region, southern New South Wales and all but the far west of South Australia (Rodman 1986). In South Australia and western Victoria this happened before the arrival of *Cakile maritima* (Heyligers 1996). Although competition between these species has been advanced as a cause of the disappearance where the two species occur together (Rodman *l.c.*), lesser fecundity, an annual lifecycle and short buoyancy and viability periods of fruits could make *Cakile edentula* more vulnerable to the effects of beach erosion. Repeated erosion at short intervals could lead to the depletion of local stock and eventual disappearance from large sections of the coast. However, *Cakile edentula* is still widespread, although not necessarily common, in Tasmania and from the North Coast of New South Wales to central Queensland.

Discussion

A closer look at dispersal from Western Australia to south-eastern Australia.

The charts of Russell (1894 – 1902) and Lenehan (1904) show that much ocean flotsam washes up on the shores of south-eastern South Australia and western Victoria. For instance, a bottle released 180 km northwest of Cape Leeuwin was picked up along Encounter Bay 18 months later; its average daily progress must have been about 5 km, a moderate figure if one considers that some bottles averaged drift speeds of 14 km day^{-1}, comparable with the 17.5 km day^{-1} attained by drifter buoys (Hahn 1986). In view of their buoyancy and longevity, for *Arctotheca populifolia* achenes to survive six if not 18 months at sea appears to be quite feasible and hence, the proposition that the plants near Beachport and the large population on the Ten Mile Sandhills, to the north, (pers. obs.) originated from achenes brought in by the Leeuwin Current straight across from Western Australia to be perfectly sound. Similarly, seeds of *Euphorbia paralias* may remain afloat and viable for many years. Hence, it is certainly possible that seeds drifting across from Western Australia colonised the beaches of south-eastern South Australia, rather than propagules from the Spencer Gulf. And in view of Russell and Lenehan's results it would even appear feasible that the population at Norman Bay at Wilsons Promontory was founded by seeds of Western Australian origin that drifted into Bass Strait.

During my research in south-eastern South Australia I have found other indications for long-distance drifting from Western Australia. Some *Spinifex* (Poaceae) populations on the dunes along that coast have the appearance of hybrids between *Spinifex hirsutus* Labill., the species occurring in Western Australia and along the Great Australian Bight, and *S. sericeus* R. Br., found on the dunes of eastern Australia (Heyligers 1988). Although these species are primarily wind-dispersed, I found that mature spikelets of *Spinifex sericeus* are buoyant and stay afloat for up to three months. Typical plants of *Spinifex hirsutus* are rare in the South East; the most easterly occurrence I have seen is near the South Australian-Victorian border. Although the contact between populations of both species is likely to predate European colonisation, the scarcity of *Spinifex hirsutus* would indicate that there have only been occasional arrivals from more westerly shores.

The occurrence of the introduced succulent herb *Tetragonia decumbens* (Aizoaceae), found in 1989 at Cape Jaffa in south-eastern South Australia, could also conceivably be explained by drifting across from Western Australia (Heyligers 2002c). Indigenous to southern Africa, this species was first collected near Fremantle in 1932. It has become common in the dunes of coastal south-western Western Australia and has localised occurrences in the Adelaide region and at the NSW Central Coast, both of which are likely due to shipping. During tests some of its fruits remained buoyant for more than two years and still contained viable seed. I think it unlikely that *Tetragonia decumbens* 'escaped' from Gulf St Vincent in view of the 'locking up' phenomenon. Its occurrence at Cape Jaffa could be linked to the presence of the nearby fishing settlement of Kings Camp, but to me, the results of drift bottle and buoy releases present a compelling case for *Tetragonia decumbens* fruits drifting in on currents crossing the ocean south of the Great Australian Bight.

The influence of the Sugarloaf Point-Smoky Cape region off the northern New South Wales coast

When I was analysing the patterns of spread along the east coast, the question arose "why had *Arctotheca populifolia* and *Cakile maritima* (before being found on Bribie Island) not spread further than Smoky Cape?" Along the coast between Sugarloaf Point and Smoky Cape progress of propagules in a northerly direction appeared be impeded because the East Australian Current, as it veers away from the coast, often entrains the inshore northerly flow (Roughan & Middleton 2002). This implies that propagules would be taken further out to sea and, consequently, drifting times would become longer and chances of survival less. It may be due to the greater availability of fruits and the somewhat better chance of staying afloat longer that *Cakile maritima* fruits, rather than *Arctotheca populifolia* achenes, eventually reached southern Queensland.

The change of direction of the East Australian Current near Smoky Cape forming a barrier to northerly spread is also evident from other dispersal histories. There are few records of *Hydrocotyle bonariensis* Lam. (Apiaceae) north from this region and none of *Gladiolus gueinzii* Kunze (Iridaceae), both introduced dune plants (Heyligers 1998). The small, abundantly-produced fruits of *Hydrocotyle bonariensis* remain afloat and viable for 12 years (pers. obs.). First collected at Botany Bay in 1893 the species had become common along the NSW Central Coast by 1917 and had reached the Smoky Cape area by 1964. The first positively identified *Hydrocotyle bonariensis* collection from Queensland came from Cooloola in 1971, with two collections from Moreton Island in 1980. Some corms of *Gladiolus gueinzii* stay afloat and remain viable for seven months (Heyligers 2000). The first collection of this speeies was made at Stockton, north of Newcastle, in 1950. It was collected near Smoky Cape in 1964 and was still there in 1985. The history of dispersal for these two species along the east coast is similar to that of *Cakile maritima*, *Cakile edentula* and *Arctotheca populifolia*, which strongly suggests that the marked changes in the flow of the East Australian Current have a bearing on dispersal.

Although the map in Smith (1991) shows that the greatest variety of tropical disseminules is found north of Smoky Cape, the presence of fruits and seeds among stranded flotsam as far south as Mallacoota demonstrates that the blocking influence of the East Australian Current is not absolute. A few of the 1200 plastic drifters released during September–October 1966 in the southern region of the Great Barrier Reef stranded along the NSW east coast, as far south as Jervis Bay (Woodhead 1970). In contrast, drift bottles and cards released in Bass Strait have been recovered as far north as Cape Tribulation (Fig. 13) showing the potential reach of propagules moving northward. That none of the species in this paper has made a comparable big leap northward shows that propagules are even more vulnerable to the vagaries of the sea than bottles or cards.

Conclusion

Dispersal is an ongoing process. One may expect the western form of *Arctotheca populifolia* to turn up on Wilsons Promontory and, given time, along the NSW east coast where it will meet the eastern form of the species. Intermingling of populations could have interesting consequences. One may also expect *Euphorbia paralias* to continue its northerly spread along the NSW coast and, like *Cakile maritima*, into Queensland. Will these species follow *Cakile edentula* into the Great Barrier Reef region? Time will tell.

Given that *Euphorbia paralias* has already spread to Lord Howe Island, will it appear in New Zealand? The fact that several drift bottles and cards released in Bass Strait were recovered along New Zealand shores and a few plants of *Atriplex cinerea* Poiret (Chenopodiaceae), an Australian coastal species, have been found along Cook Strait (Heyligers 2001) makes this more than a hypothetical question.

These days introduced species are eyed with suspicion and some dealt with in this paper are no exception. The *Cakile* species have been too long in Australia to attract much attention and are sometimes even thought to be native! In contrast, *Euphorbia paralias*, a more recent arrival, has been subject to local eradication campaigns (Heyligers 2002a). Given the dispersal capacity of this species, it should be clear that such efforts will meet limited success as recolonisation will be ongoing. It may be of help to know, that although I do not deny that these introduced species do change the composition of the herbaceous foredune flora, all four are shade-intolerant and succession by woody species will automatically suppress and, if sufficiently dense, eliminate them.

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Appendix 1 Commentaries on the results of drift bottle and drift card releases (Figs. 9–13)

Commentary on Figure 9

Strandings from bottles released near Bathurst Light revealed the existence of a northerly longshore current, while prevailing wind directions caused the seasonality apparent in the stranding locations. Bottles released off Cape Naturaliste between August and November drifted past Cape Leeuwin and like those released off Cape Leeuwin followed an easterly course under the influence of the Leeuwin Current. Further east, this current separates from the coast and consequently, from the 15 batches released between April and September near Eclipse Island, only single bottles from six batches were recovered, near Bremer Bay and at Eucla. Bottles from batches released at other times usually floated in a northerly or north-easterly direction under the influence of southerly winds.

Commentary on Figure 10

Drift bottles released from May to early October floated mainly into Bass Strait, but those released later in October and during the following months drifted north, some as far as the southern beaches of Eyre, Yorke and Fleurieu Peninsulas and Kangaroo Island, thus demonstrating the influence of the seasonal Flinders Current.

Commentary on Figure 11

The results of simultaneous releases demonstrate the variability of currents in the Strait. Stranding locations of both types of bottles sometimes coincided, but on other occasions differed greatly, apparently mainly due to wind conditions. Coinciding strandings over a limited stretch of coast, for instance from the May and October releases, were preceded by a spell of strong winds from the quarter opposite to the drift direction. Under these conditions deeper floating ballasted bottles were transported in the same direction as empty bottles. When winds are lighter and changeable, the drift paths of ballasted bottles are more erratic due to the greater influence of tidal currents. This is demonstrated by the March release: many empty bottles were found on the Otway coast, while ballasted bottles were recovered in the Port Fairy area as well at Wilsons Promontory.

Commentary on Figure 12

There were three recoveries outside Tasmania, as follows: two cards from batch 29, one was found after 186 days 45 km south-west of Lakes Entrance, Victoria, the other one after 322 days near Sydney; and one from batch 40, found on the North Island of New Zealand after nearly 22 months.

From the strandings being largely confined to Tasmania's north coast it is apparent that there is little interaction between this southern part and the rest of Bass Strait. This suggests that the influence of tidal movements may be even stronger here than elsewhere in Bass Strait.

Commentary on Figure 13

The strandings demonstrate that the whole of Australia's east coast comes within the reach of drifting objects once they have left Bass Strait. However, at present there is no evidence that any of the propagules of the species discussed in this paper have made the journey to the Great Barrier Reef without 'stop-overs' and one may safely assume that the chances of surviving such a long journey are virtually nil.

Plant composition of three woodland communities of variable condition in the western Riverina, New South Wales, Australia

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Abstract: We examined differences in floristics among three regionally-threatened woodland communities in the western Riverina: Blackbox (*Eucalyptus largiflorens*), Bimble box-Pine (*Eucalyptus populnea-Callitris glaucophylla*) and Boree (*Acacia pendula*) between 2001 and 2004. Our aim was to examine possible relationships between the diversity and biomass of groundstorey vegetation, and remnant condition and rainfall both among communities and across years. The three woodland communities varied widely in their plant species composition, with only 22% of the 358 species common to all communities. Seven species, mainly exotic grasses and forbs, contributed 25% of the total cover across all sites and times. Blackbox communities had the greatest number of exotic and annual species. There were poor relationships between condition and diversity, richness, evenness or abundance of groundstorey plant species within 400 m^2 quadrats. Overall, sites in better condition tended to support a greater cover of native plants and a lower cover of exotic plants (Blackbox only). There were only weak relationships between rainfall and biomass. The marked variation in species diversity in relation to changing seasonal conditions and within similar condition classes highlights the difficulties of developing benchmarks for separating the effects of management, and seasonal and longer-term climate change.

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Introduction

Over the past century the wheat-sheep belt of south-eastern Australia has undergone substantial modification, predominantly through the clearing of vegetation for agriculture. Fertile soils of the western slopes of the Great Dividing Range have suffered dramatic reductions in natural vegetation, with up to 95% removed in some districts (Murray-Darling Basin Ministerial Council 1987, Walker et al. 1993). The removal of large areas of native woodland is exacerbated by the fact that <1% of the native vegetation communities in the NSW Southwest Slopes Bioregion are formally reserved (Thackway & Cresswell 1995) and only small areas of woodland in the eastern sections of the Riverina Bioregion are reserved (Eardley 1999). In particular, fertile soils supporting box woodlands on flat and gently undulating slopes have been extensively cleared for agriculture, with a result that <2% of the original extent of *Eucalyptus melliodora* woodlands remains (Sheahan 1998). Similarly <0.1% of the original grassy white box (*Eucalyptus albens*) woodlands remain in near-natural condition (Prober & Thiele 1995).

Most remnants are also severely degraded, and intact communities with native groundstorey and shrub layers are now extremely rare (Lunt 1991, Curtis & Wright 1993, Prober & Thiele 1995, Spooner et al. 2004). Degradation of vegetation is associated with increased land degradation (Bird et al. 1992), with increasing woodland fragmentation, increasing numbers of isolated trees, declining tree health, reduced tree recruitment, loss of understorey plants, rising water tables causing salinity and waterlogging, soil erosion, deterioration of soil structure, invasion by exotic plant species and an increase in unpalatable understorey species (Yates & Hobbs 1997). This loss of native vegetation is also associated with a decline in ecosystem function, the ability of the landscape to cycle nutrients, resist erosion and to produce biomass, and therefore a reduction in the quality of habitat for plants and animals. With ongoing clearing, fragmented patches of woodland are increasingly being isolated from related patches, resulting in habitat discontinuity (Bennett 1990). Smaller remnants have higher edge to area ratios, meaning that they are almost entirely edge habitat. Edges may have differences in micro-climate variables, wildlife species and differences in plant structure and composition (Bennett 1990). They are more susceptible to invasion by feral plants and animals (Loney & Hobbs 1991) and consequently tend to support a greater number of weedy plants (Panetta & Hopkins 1991).

In the Murrumbidgee Irrigation Area (MIA) in the western Riverina region of southern NSW, the Bimble box (*Eucalyptus populnea*) – Pine (*Callitris glaucophylla*) and Boree (*Acacia pendula*) communities are regarded as Endangered, i.e. there is < 10% of pre-European extent remaining, and the Blackbox (*Eucalyptus largiflorens*) community is Depleted i.e. 30–50% of pre-European extent remaining (WRRVMC 2001, Benson et al. 2006). The Blackbox community corresponds mainly with ID13 and ID16, but there are also smaller areas of ID15 of the New South Wales Vegetation Classification (Benson 2006, Benson et al. 2006). The Boree community corresponds with ID26, and the Bimble box-Pine community mainly with ID82 of the Vegetation Classification (Benson et al. 2006). The MIA was originally developed as an irrigation district in the middle of the 20th century, and has been extensively cleared to support horticulture, orchards, and more recently, rice farming. Blackbox and Boree communities have suffered substantially from clearing for irrigation because the fine-textured soils on which they occur are highly suitable for irrigation Bimble box-Pine communities tend to occur on the higher level undulating plains and footslopes, and are generally less suitable for irrigated agriculture. However they have been subjected to overgrazing and vegetation removal to increase carrying capacities for sheep grazing.

Apart from some National Parks and State Forests (e.g. Cocoparra National Park, Binya State Forest), few large tracts of intact woodland remain in the MIA. Many of the smaller patches have been severely degraded due to a combination of overgrazing, selective clearing, removal of the shrub layer and alterations to natural flooding regimes due to changing irrigation practices. Close to the irrigation areas, saline water tables occur within the rooting zone of trees. Consequently the trees are generally in poor health (Harrison 2001, Eldridge 2002). Similarly, many large and generally intact remnants are characterised by a depauperate groundstorey vegetation community, largely though overgrazing. Overgrazing causes palatable native forbs and tall perennial grasses to be replaced by small tussock-grasses and then introduced annual grasses and herbs (Moore 1970, Lunt 1991, Prober et al. 2002), ultimately increasing the proportion of annual exotic plants at the expense of natives and perennials (e.g. Grice & Barchia 1992, Navie & Rogers 1997).

Here we report on a study of the floristics of three regionally important woodland communities in the southern Riverina for which little information is available. The aims of this study are threefold: (1) to examine differences in floristics among the vegetation communities and across years, (2) to examine possible relationships between remnant condition and the attributes of the groundstorey vegetation, and (3) to explore possible relationships between rainfall and groundstorey vegetation.

Methods

Study sites

The study was part of a larger biodiversity monitoring program designed to assess condition, in the context of biodiversity, in seven vegetation communities in the western Riverina. The study was conducted at 42 remnant patches of Blackbox, Bimble box-Pine and Boree within 30 km of Griffith in south-western New South Wales, Australia (34° 05–35'E, 145° 35–146° 08' S). The Blackbox community is restricted to plains, floodplains and relict drainage channels, often with a characteristic gilgai pattern ranging from small crabholes about 30 cm across to wide melon holes and sinkholes up to 20 m across and 1 m deep. Soils are predominantly medium to heavy grey clays (Ug5.24, Ug5.25, Ug5.28; Northcote, 1992), sometimes overlain by clay loams and loams. Slopes were generally less than 1%. Erosion was typically low on the clay soils (<5%), and restricted to the boundary between sandy soils which occur on the margins of the aeolian country. The soils are stable and generally fertile, with high levels of organic carbon (mean = 5.9%).

The Bimble box-Pine community occurs over extensive areas of slightly undulating plains, footslopes and midslopes on deep, loamy calcareous earths (Gn2.12, Gn2.13; Northcote 1992). Often the soil profile has calcareous material at depth. Adjacent to the ranges, soil profiles are dominated by colluvial material eroded from the higher slopes. In many places rock outcrops occurred over 5–10% of the site. On steeply sloping country with little vegetation cover, calcareous red earths are moderately susceptible to gullying, rilling and water sheeting. The soil surface is often dominated by biological soil crusts at cover levels up to 60% (Eldridge 2002). The Boree community occurs on floodplains with gilgai to 1 m across, elevated plains with source-bordering dunes, or the levees of prior streams. Soils range from compacted grey clays (Ug5.24, Ug5.28) to sandy and loamy duplex soils on the prior stream levees (Dr2, Db2, Db4). Boree (*Acacia pendula*) occurs at relatively low densities (< 50 trees ha^{-1}). Shrubs such as cassia (*Senna artemisioides*) and hopbush (*Dodonaea viscose*) occur in moderately high densities at some sites. Common groundstorey species (by cover) included burr medic (*Medicago polymorpha* var. *vulgaris*), climbing saltbush (*Einadia nutans*), great brome (*Bromus diandrus*), ruby saltbush (*Enchylaena tomentosa*) and corrugated sida (*Sida corrugata*).

Site selection

We compiled a list of potential woodland sites by digitising onto maps clearly-defined remnants of native woodland vegetation greater than 1 ha in area. The vegetation community characterising these remnants was identified using local knowledge and some ground-truthing. We then used a simple matrix of eight attributes to guide our selection of potential monitoring sites. These attributes were: patch size, connectivity (distance to the nearest patch of similar vegetation), depth to the water table, degree of grazing, tree health, extent of shrub regeneration, extent of tree regeneration, and weediness. The value of each attribute was rated from 0 to 3, with higher ratings corresponding to healthier or more intact sites. For a potential site, the values for each attribute were summed, and expressed as a percentage of 24, the maximum score for any site. For example, a 23 ha site (rated 2 for size), 70 m distant from the next nearest patch (rated 2 for connectivity), with water table at 1.7 m (rated 1 for water table depth), ungrazed (rated 3 for grazing status), with healthy tree canopies (rating = 3), abundant tree regeneration (rating = 3), few shrubs (rating = 1) and < 10% weeds (rating = 3) would receive an overall score of 2 + 2 + 1 + 3 + 3 + 3 + 1 + 3 (=18) out of a possible score of 24; therefore a value 75 %. A final decision on which sites to monitor from within each woodland community was made by examining the site scores obtained using the process described above. As the aim of the study was to select sites with a range of intactness or condition, we selected sites with a wide range of scores.

Scores for Blackbox sites ranged from 8% (small degraded sites) to 87% (large and intact), Bimble box-Pine from 43% to 100%, and Boree sites from 38–75%. From this process we selected a total of 20 Blackbox, 13 Bimble box-Pine and nine Boree sites. Equal numbers of Blackbox sites (*n*=5) were ungrazed, lightly grazed, moderately grazed and heavily grazed. For the Bimble box-Pine communtiy, five sites were heavily grazed, two moderate, one light and five ungrazed. Three Boree sites were moderately grazed while the remainder were heavily grazed (two sites), lightly grazed (two sites) or ungrazed (two sites).

The vegetation survey

At each site we established a 20 m by 50 m plot, within which was centrally located a 20 by 20 m plot. The larger plot was selected to be as representative as possible to the site conditions. Projected foliage cover of all vascular plants was measured, by species, within a 20 m by 20 m plot. The projected foliage cover of all woody plants (shrubs and trees) was measured in a 20 by 50m plot. Biomass of groundstorey vegetation was assessed using a series of photo-standards developed for grasslands and woodland further west (Eldridge & Koen 2003). Sites were measured in early spring, generally September to October. Monthly rainfall over the period is shown in Figure 1.

Site-based condition assessment

Each site was given a subjective score for condition (in the context of biodiversity) when the site was visited, but before measurements were made. The score was based on the senior author's impression of the status of the site, from personal experience with the soils and vegetation of the area, and took into account attributes such as the health of the trees (Wylie et al. 1992) and shrubs, the diversity and floristics of the groundstorey vegetation, the stability of the soil, the presence of weeds and the presence of perennial plants. The scores assigned ranged from very poor condition (rating = 1) to excellent condition (rating = 10). Scores were assigned at each time of measurement. We acknowledge potential problems with a heuristic approach to assessing condition, not the least being the potential for the introduction of personal biases (Oliver et al. 2007). However, in this study all sites were assessed by one observer, and while a different 'expert' might be expected to assess the sites slightly differently, we are confident that the overall ranking would be the same. The Blackbox and Bimble box-Pine sites were measured annually from 2001–2003. Six Boree sites were measured between 2001 to 2003 and an additional three sites added in 2002 and measured thereafter yearly until 2004.

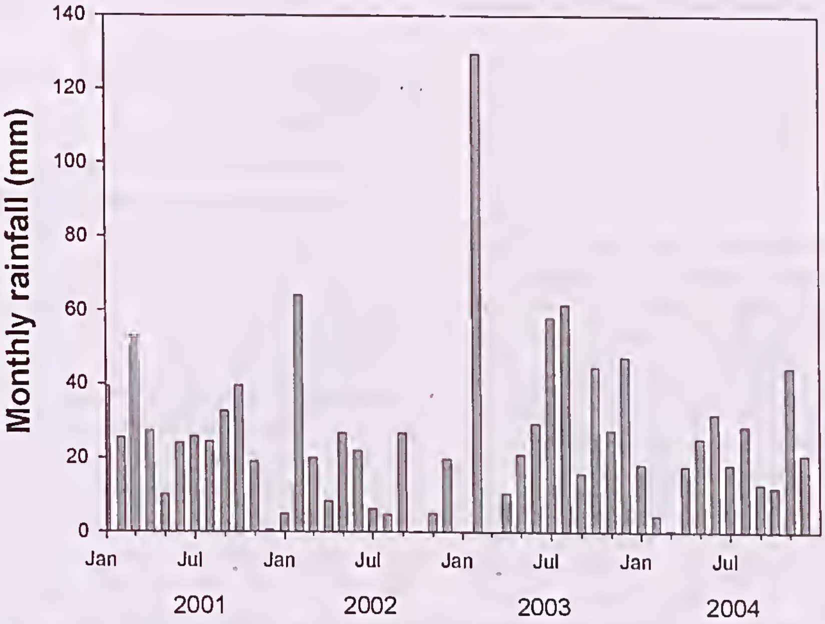

Fig. 1. Monthly rainfall (mm) for the four-year period (2001–2004). Measurements were made between September and October in all years.

Statistical analyses

We used a combination of multivariate and univariate statistics to examine the differences in floristics between the three woodland communities, and relationships between floristics and diversity and other environmental variables. We converted a matrix of 358 columns (plant species) by 126 rows (sites by visits) to a similarity matrix using the 4th-root transformation and the Bray-Curtis distance measure using Canonical Analysis of Principal Coordinates CAP statistical package (Anderson 2004). Canonical Analysis of Principal Coordinates combines the use of principal coordinate analysis with either a canonical discriminant analysis (when the hypothesis concerns groups) or a canonical correlation analysis for exploring relationships with environmental or other variables; Anderson and Willis 2003). It tests the significance of these groups, defined *a* priori, using a canonical test statistic. The degree of association of individual species with either Blackbox, Bimble box-Pine or Boree communities was assessed using Indicator-Species Analysis using PC-ORD (McCune & Mefford 1999). Indicator values combine information on relative abundance and frequency of species. For example, when all individuals of a given species are restricted to a particular class, and all samples from the particular class contain an occurrence of that species, then the indicator value is maximal, i.e. IV=100. Species data were randomized among the soil texture, rainfall and forestry practice classes, and a Monte Carlo randomization procedure performed with 1000 iterations in order to determine the statistical significance of the indicator values. The PCORD software was also used to generate information on plant diversity at each site and time, i.e. the number of species, richness and evenness. Relationships between diversity measures between the three communities were examined using one-way ANOVA (Minitab 1997) after using diagnostic tests to check for homogeneity of variance and normality.

Results

Community composition

The three woodland communities varied significantly in their plant species composition, and the two canonical test statistics were highly significant (P=0.0001 for both tests, using 9999 permutations; Figure 2). There were some significant differences between years (P=0.001), though surprisingly they were not very strong considering the dry conditions in 2002. All years except 2004 different from all other years. Indicator species analysis indicated that *Eucalyptus largiflorens* (IV=100, P=0.001), *Hordeum leporinum* (IV=62, P=0.001), *Malva parviflora* (IV=52, P=0.001) and *Marsilea drummondii* (IV=50, P=0.001) were the main indicators of Blackbox sites. *Callitris glaucophylla* (IV=69.4, P=0.001), *Cheilanthes sieberi* subsp. *sieberi* (IV=66.5, P=0.001) and *Eucalyptus populnea* (IV=52.2, P=0.001) were the best indicators of Bimble box-Pine sites. The community dominant, *Acacia pendula* (IV=90, P=0.001), was a good indicator or Boree sites, along with the chenopod forb *Atriplex semibaccata* (IV=41.3, P=0.001). *Avena* spp. (IV=54, P=0.005) and *Austrodanthonia caespitosa* (IV=50, P=0.009) were strong indicators of 2001, while *Echium plantagineum* (IV=56, P=0.029) and *Calotis hispidula* (IV=55, P=0.007) were good indicators of 2003.

A total of 358 species was recorded among the three woodland communities over the four years of measurements. Seventy-eight species (22%) were found in all communities, 86 (24%) in two communities and 194 (54%) in only one community. A total of 218 and 240 species was recorded from the Blackbox and Bimble box-Pine communities respectively, and 180 species from the Boree community. About 25% of total cover recorded across all sites and times was contributed by seven species (*Lolium perenne, Hordeum leporinum, Echium plantagineum, Austrostipa scabra, Bromus diandrus, Sisymbrium* sp., *Arctotheca calendula*), all of which were found in all three communities.

There were significantly fewer species per quadrat in the Blackbox community (24.9 ± 1.37 mean ± SEM) compared with Bimble box (32.1 ± 1.73) or Boree communities (30.0 ± 1.42; $F_{2,123}$=6.79, P=0.002). The trend was similar for richness ($F_{2,123}$=10.95, P<0.001) and evenness ($F_{2,123}$=8.02, P=0.001). Across all vegetation communities there were significantly fewer species per quadrat in 2002 (20.0 ± 1.26) compared with the other years (32.3 to 35.0; $F_{3,122}$=18.6, P<0.001). Blackbox communities supported the highest percentage of exotic species (43.1%) compared with Boree (31.7%) or Bimble box-Pine (26.7%, $F_{2,123}$=10.9, P<0.001). The Blackbox community also had a greater proportion of annuals (39.8%) compared with Bimble box-Pine (32.5%; $F_{2,123}$=3.9, P<0.023). Bimble box-Pine sites supported twice the number of perennial grass species (7.8 species) compared with the Blackbox sites (4.9 species; $F_{2,123}$=13.2, P<0.001).

Plant cover and diversity in relation to condition and tree cover

Over all communities and across all sampling dates, there was a moderately positive relationship between the condition scores and the cover of exotic plants found within a quadrat ($F_{1,124}$=32.2, P<0.001, R^2=0.20). Analyses for the Blackbox sites only revealed that increasing condition was associated with a declining cover of exotic plants ($F_{2,57}$=20.2, P<0.001, R^2=0.43; Figure 3). Further, when condition scores were amalgamated into three groups that were determined, *a priori*, to correspond to obviously differences in condition (i.e. <5.1 = poor condition score, 5.1–6.9 = average condition, >6.9 = good condition), exotic plant cover averaged 17% on good condition sites compared with 62% on poor and 51% on average condition sites ($F_{2,57}$=4.35, P=0.017). Native plant cover increased slightly with increases in condition ($F_{1,58}$=15.0, P<0.001, R^2=0.19), but the range of cover increase was very small (Figure 3).

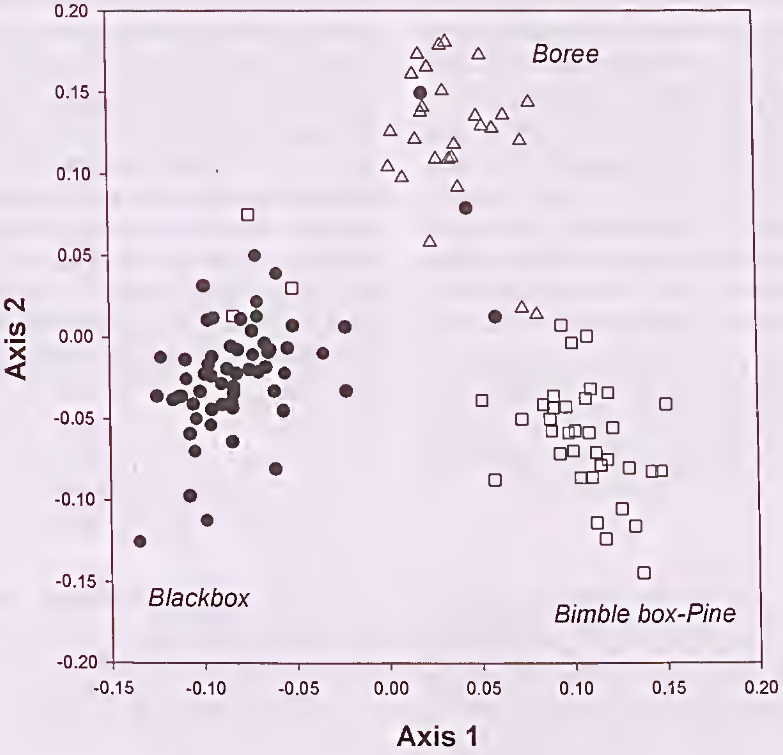

Fig. 2. Plot of the first two canonical axes produced by the CAP analysis showing the separation of the three woodland communities in relation to the 358 plant species. Closed circle = Blackbox community, triangle = Boree community, open circle = Bimble box-Pine community.

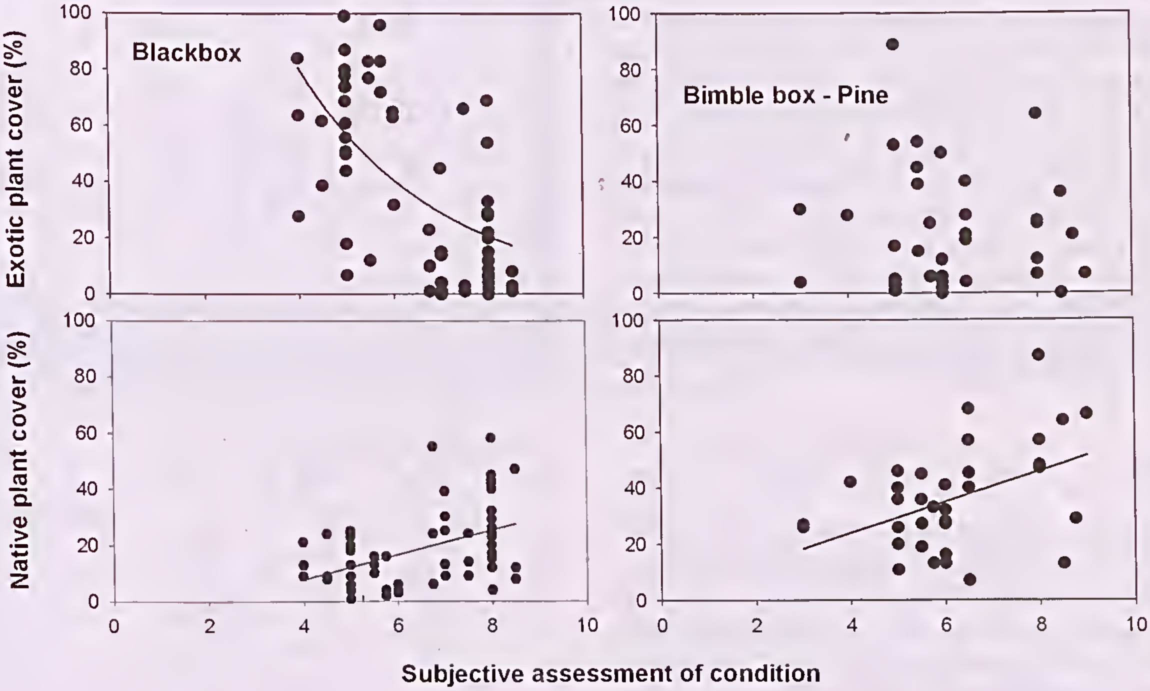

Fig. 3. Relationships between the subjective assessment of condition (increasing number equates with a healthier site) and the cover of exotic and native groundstorey plants in Blackbox and Bimble box-Pine communities. Relationships for Boree community were not significant.

For the Bimble box-Pine sites there was no significant relationship between exotic plant cover and condition, but increases in condition were associated with increased cover of native plants ($F_{1,34}$=8.4, P=0.006, R^2=0.18; Figure 3). Good condition Bimble box-Pine sites supported 40% more groundstorey species ($F_{2,36}$=3.72, P=0.034) and 48% more native groundstorey species ($F_{2,36}$=5.44, P=0.009) compared with sites in poor or average condition (Table 3). Overall, Bimble box-Pine community sites in better condition tended to produce more plant biomass ($F_{1,37}$=12.2, P=0.001, R^2=0.23), but these trends were not evident on Blackbox or Boree sites.

Increases in tree cover were associated with declines in the diversity of understorey plants in 2001 ($F_{1,37}$=4.42, P=0.042), though the predictive power was very poor (8%), and 2002 ($F_{1,40}$=18.81, P<0.001, R^2=0.30). Relationships were not significant in 2003 (Figure 4).

Rainfall effects

We expected strong relationships between rainfall and measures of quadrat-based diversity, cover and biomass. However, rainfall 3 and 6 months prior to measurements explained 22% and 26% respectively of the variation in the total number of groundstorey plants recorded per quadrat in the Blackbox community ($F_{1,58}$=17.7–21.2, P<0.001). However, for the Bimble box-Pine and Boree communities, no significant relationships could be detected between rainfall and plant diversity for lag periods up to 12 months prior to field survey.

Pooled across all sites and sampling dates, we were unable to predict the biomass of groundstorey plants using rainfall 3–, 6– or 12–months prior to measurements. Similarly, no trends were apparent when the data were analysed separately for poor, average or good condition sites (e.g. Blackbox sites). We did, however, find that for the Blackbox community, increases in rainfall over and above 90 mm received during the previous 3 months were associated with increased biomass, but only at the good condition sites ($F_{1,11}$=7.2, P=0.02, R^2=0.34). There were no similar responses for poor or average condition sites, and for both Bimble box-Pine and Boree communities, biomass was largely independent of rainfall in the past 3 months.

Discussion

In our study we detected large differences in floristics between the three vegetation communities with a strong group fidelity, and only 22% overlap in species across the three vegetation communities. The overlapping group came from a wide variety of plant types, including some annual, often weedy European exotics such as *Medicago* spp., *Vulpia* spp., *Avena, Sisymbrium* and *Arctotheca calendula*, but also the ubiquitous perennial native grasses and forbs such as *Austrodanthonia, Austrostipa, Enteropogon, Chloris, Oxalis perennans*, and the sub-shrubs *Maireana* spp. and *Einadia nutans* var. *nutans*. The high level of agreement for the majority of plant species (78%) suggests to us that inherent abiotic differences between the communities (e.g. soil texture and depth, parent material and geomorphic location) account for the major differences in the distribution of species. Averaged across all years, the families Poaceae, Chenopodiaceae and Brassicaceae dominated the understorey of Blackbox communities, Poaceae, Asteraceae and Cupressaceae understorey of Bimble box-Pine sites, and Poaceae, Fabaceae and Chenopodiaceae the understorey Boree sites. This is similar to results from other studies in southern NSW (e.g. Porteners 1993, Sivertsen & Metcalfe 1995) for the Riverine Plain and southern wheat belt regions respectively.

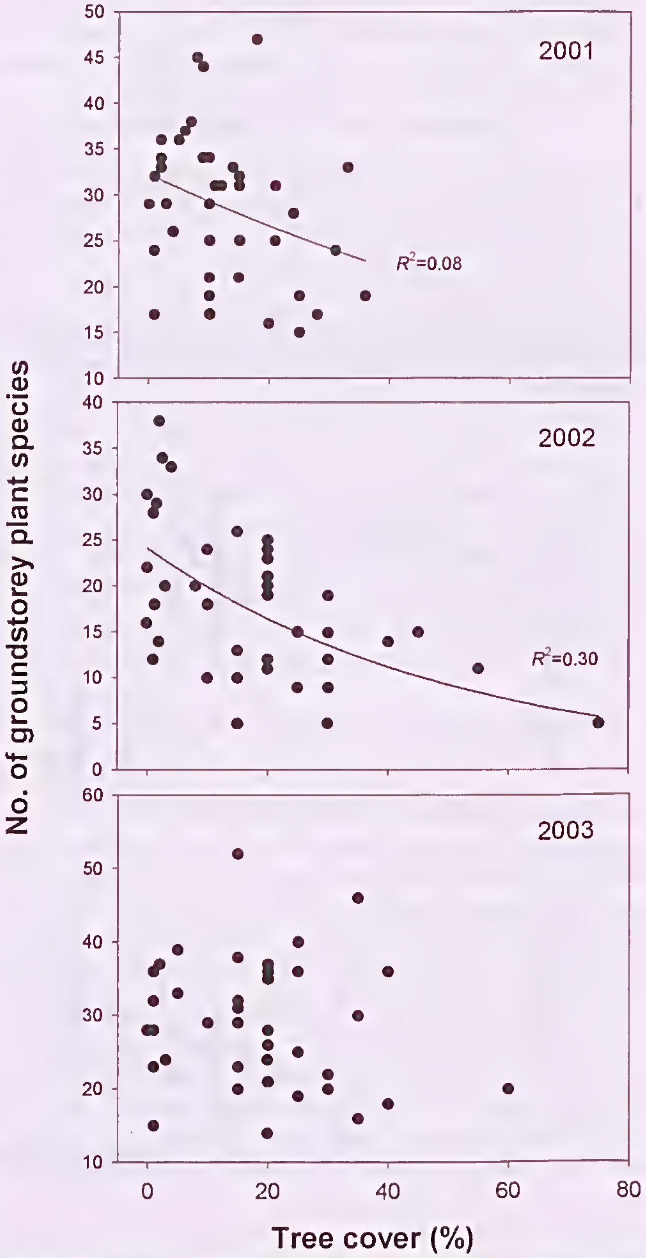

Fig. 4. The diversity of groundstorey plant species in relation to tree cover (%) in 2001, 2002 and 2003. Data for the three communities have been pooled.

Rainfall had only a weak influence on plant diversity and biomass, but consistently fewer species, and a greater proportion of perennials and native plants were recorded in all communities in 2002 compared with 2001 or 2003 (Table 1). Seasonal conditions were exceptionally dry in 2002, with Griffith receiving only 46% (193 mm) of its average annual rainfall. The groundstorey vegetation was dominated almost exclusively by the aggressive cool-season annuals *Echium plantagineum, Hordeum leporinum, Avena* spp., *Bromus diandrus, Sisymbrium irisymoides, Vulpia* spp. and *Carthamus lanatus*, and this trend was consistent across the three vegetation communities. We expect that other cool-season native annuals such as *Goodenia, Rhodanthe, Atriplex, Calocephalus, Pseudognaphalium, Cotula* and *Harmsiodoxa* spp., which were common in other years, would have disappeared more rapidly in 2002 because of a lack of sufficient soil moisture to sustain them into the spring.

That we failed to find any reasonable relationships between rainfall and diversity, or rainfall and biomass, is surprising given the generally widely-accepted relationship between increasing rainfall amount and increasing plant production (e.g. Noble & Crisp 1981, Southgate et al. 1996, du Plessis 1999). Extensive data on the relationships between rainfall and biomass production for well-managed semi-arid grazing lands suggest an efficiency of 30–60 g plant dry matter m^{-2} mm^{-1} rainfall (Le Houérou 1984). As these relationships have been developed over long time periods, their predictive power in understandably likely to be low in specific years or at specific locations. We posited that potentially there could have been interactions between grazing and biomass production, such that any reductions in biomass at grazed sites might have negated potential increases at lightly grazed (ungrazed) sites. Also, there were large populations of kangaroos in many remnants, and consequently, heavy grazing pressure during dry times. However, partitioning sites by grazing intensity failed to improve the relationships between rainfall and biomass production

Tree density could have been an important determinant of the effect of rainfall on biomass and diversity, particularly in landscapes where grazing by domestic herbivores is low or absent (e.g. Chilcott et al. 1997, Gibbs et al. 1999. Ludwig et al. 2001, Dorrough *et al.* 2006). While we found that increasing tree cover had no apparent effect on understorey

Table 1. Attributes of the vegetation in the three woodland communities. [a] condition of the tree canopy assessed after Wylie et al. (1992); maximum score = 6 (fully foliaged), minimum score = 1 (dead, defoliated).

Attribute	Vegetation community									
	Blackbox			Bimble box-Pine			Boree			
	2001	2002	2003	2001	2002	2003	2001	2002	2003	2004
No. of species	30.1	15.3	29.2	35.3	23.9	37.0	33.7	24.8	32.1	35.0
% perennials	60.6	68.8	51.2	66.4	71.1	65.2	61.3	67.4	60.8	62.2
% natives	55.4	64.7	50.6	68.2	78.3	73.5	64.3	71.3	68.9	66.5
Tree condition[a]	4.5	3.9	4.8	5.3	5.0	5.0	5.0	5.1	5.0	5.9

Table 2. Mean (± standard error of the mean; SEM) and range of species richness for all groundstorey plants and native groundstorey plants in 400 m^{2} quadrats from poor (condition score <5.1), average (5.1–6.9) and good (>6.9) sites in the three woodland communities. For a particular community, different subscripts indicate a significant difference in the number of species between condition classes at $P<0.05$. [#] includes native and exotic species.

Condition	All groundstorey plants[#]				Native groundstorey plants			
	Mean	SEM	Min	Max	Mean	SEM	Min	Max
Bimble box-Pine								
Poor	25.1^{a}	3.2	14	52	17.9^{a}	2.6	8	40
Average	26.7^{a}	1.7	16	36	17.8^{a}	1.3	9	31
Good	35.3^{b}	3.2	19	45	26.4^{b}	2.0	13	33
Blackbox								
Poor	22.4^{a}	1.7	5	37	9.8^{a}	1.2	2	21
Average	19.7^{a}	2.3	10	36	10.9^{a}	2.0	3	28
Good	23.8^{a}	2.5	5	47	15.2^{b}	1.3	4	27
Boree								
Poor	28.7^{a}	6.3	20	41	18.7^{a}	3.8	13	26
Average	34.7^{a}	2.7	15	42	24.7^{a}	1.7	15	31
Good	28.8^{a}	1.7	16	39	19.6^{a}	1.3	15	39

biomass, there were moderate effects on diversity. We detected general declines in diversity with increasing tree cover for all communities and years, but none of the relationships was significant ($P>0.05$) when data for the three communities were examined separately. However, when we grouped together data for all woodland sites, increasing tree cover was associated with weak exponential declines in groundstorey plant diversity in 2001, no significant relationship in 2003, but a relatively strong relationships for the dry year of 2002 ($R^2=0.30$; Figure 4). This is an important and interesting finding, and suggests that the effect of tree cover on understorey diversity is moderated by available soil moisture. In below-average rainfall years, trees appeared to be competing with groundstorey plants, probably for moisture, as this is a critically-limiting resource in semi-arid environments. Observations of dense swards of annual grasses and forbs, particularly *Avena* spp. and *Sisymbrium* spp. under tree canopies in average or high rainfall years suggests a groundstorey plant response to moisture, but probably also nitrogen and carbon, which are known to accumulate under tree canopies (Prober *et al.* 2002, Eldridge & Wong 2004). It is unlikely that trees diminished nitrogen levels greatly, given the fact that many plants recorded in the dry year were annual Mediterranean weeds, which would be expected to have had a high demand for soil nitrate.

Undoubtedly, understorey plants would have benefited from being close to trees by being able to access water drawn from deeper layers by hydraulic lift (Caldwell & Richards 1989). Pools of organic matter would have contributed to greater carbon, nitrogen, phosphorus and potassium pools under trees compared with in the open (Prober et al. 2002, Eldridge & Wong 2004), the result of stem flow processes, the trapping of dust, and increases in litter and soil organic matter at the base of trees (Munzbergova & Ward 2002), all of which are processes mediated directly by the trees themselves (Deans et al. 1999). This will eventually lead to the development of fertile patches around the trees, areas of enhanced soil nutrients (Gersper & Holowaychuk, 1971, Rhoades, 1997), which in agricultural areas, are often dominated by a halo of dense annual grasses (Prober *et al.* 2002). Our data suggest that the extent to which understorey plants benefited from proximity to tree canopies depends on seasonal conditions.

This study also highlights the relationships between condition assessed at the site level and the diversity of groundstorey plants. In the Blackbox community in particular, quadrats from sites in good condition supported about 50% more native plants compared with those from poor or average condition sites (Table 2). However, the relationships were very weak for the Bimble box-Pine sites. While we acknowledge that condition is highly subjective and often value-laden and context-dependent (Oliver 2002), our subjective assessment of condition was nonetheless highly correlated with indicators of functional, highly organised landscapes (Eldridge 2002). Apart from a greater proportion of native plants, quadrats in good condition sites had significantly greater cover of perennial plants, greater foliage and basal cover of perennial grasses, and more patches in the landscape, all characteristics that we would attribute to healthy sites. Although there were a few large patches of Blackbox in the study area, many sites were small and adjacent to cultivated farms, and although effectively ungrazed, were severely degraded due to their small size and proximity to roads. The Boree sites were similar, occurring as very small, highly degraded patches, with their present status less than 30% of its pre-European extent (WRRVMC 2001).

The study can improve our understanding of the variability in species cover and diversity across three important woodland communities of variable condition in the Riverina. We showed that an extensive cover of native plants is a useful indicator of condition for Blackbox sites, while exotic plant cover is indicative of degraded sites, particularly in the Bimble box-Pine community (Figure 3). However, plant diversity was less informative, and while there were differences in mean diversity between good and poor condition sites (Table 2) the range in diversity for Blackbox sites (4–27 species per quadrat for good condition sites) was close to that of poor condition sites (2–21 species per quadrat; Table 2). The marked variation in species diversity in different seasons, and the large overlap in diversity for sites of different condition highlights the difficulties of developing benchmarks for separating out the effects of management from seasonal effects and longer-term climate change. This reinforces the view that benchmarking of these communities will not be easy.

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Is there a close association between 'soils' and 'vegetation'? A case study from central western New South Wales

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Abstract: The assumption that 'soils' and 'vegetation' are closely associated was tested by describing soils and vegetation along a Travelling Stock Reserve west of Grenfell, New South Wales (lat 33° 55'S, long 147° 45'E). The transect was selected on the basis of (a) minimising the effects of non-soil factors (human interference, climate and relief) on vegetation and (b) the presence of various soil and vegetation types as indicated by previous mapping. 'Soils' were considered at three levels: soil landscapes (a broad mapping unit widely used in central western NSW), soil types (according to a range of classifications) and soil properties (depth, pH, etc.). 'Vegetation' was considered in three ways: vegetation type (in various classifications), density/floristic indices (density of woody species, abundance of native species, etc.) and presence/absence of individual species. Sites along the transect were grouped according to soil landscapes or soil types and compared to vegetation types or indices recorded at the sites.

Various measures indicated low associations between vegetation types and soil landscapes or soil types. Except for infrequent occurrences of a soil type or landscape, any one soil type or landscape was commonly associated with a number of vegetation types and any one vegetation type was associated with a number of soil landscapes or soil types. However, significant associations between some vegetation indices, mainly density or numbers of woody species, and some soil landscapes and soil types were evident. Although many species were relatively ubiquitous, some groups of species that were restricted to one or two soil types were identified. Canonical Correspondence Analysis provided some suggestions as to which properties (e.g. texture) of these soils were associated with the presence of particular species.

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Introduction

As soils are the most common terrestrial substrate for plant growth, it would seem logical that their properties (texture, structure, depth, nutrient status, etc.) would have a major influence over which species become established and persist thus on the structure and floristics of the vegetation at any site. Soils and vegetation are also theoretically dependent on the same independent factors: parent material, topography, climate, organism-availability and time.

Dominant plants, especially eucalypt species, were reported (Bower *et al.* 2002) to have guided the early settlers in their selection of suitable lands ('soils') for grazing and/or agriculture in central western New South Wales (NSW). Vegetation has also been used by soil surveyors as a guide to soil type (Chapman and Atkinson 2000). It is therefore surprising that following an extensive survey of soils and vegetation in western NSW, Beadle (1948, p. 49) reported:

> "*While it is true that climate partly determines not only the soil characters (parent material in western New South Wales, at least, plays an equally important part) but also the nature of the vegetation, the relationships that exist between the vegetation and the soil are so ill-defined that to use one as an indicator of the other (except in a very broad sense) will lead to a misrepresentation of the true conditions.*"

Vegetation types, he claimed, reflected water availability, which is mainly a function of rainfall and soil texture with the latter being mainly a function of parent material. He did, however, report relationships between some species and soil properties (texture, pH and drainage). By contrast, Moore (1953) reported a close relationship between Great Soil Groups and vegetation alliances in the Riverina district further to the east.

It could be argued that some natural associations between plant and soils may have been obliterated by the activities of European man. Direct effects include the deliberate replacement of one vegetation type by clearing and/or changed grazing regimes, and soil compaction by introduced herbivores leading to increased runoff to depressions (and a more assured water supply for early settlers; Heathcote 1965, p. 26). Indirect effects include the local extinction of ground-foraging marsupials that were believed to have an important role in rainfall infiltration and nutrient cycling (Martin 2001). In many cases, changes were brought about inadvertently during drought when overgrazing or cultivation led to soil erosion and/or permanent changes in the composition of vegetation. Other examples of the effects of these predominantly European introductions on soils are provided by Russell and Isbell (1986), and on vegetation by Anderson (1941) and Benson (1991). However, the nature of the pre-European settlement vegetation and particularly the role of fire in its maintenance have been the subject of heated debate (e.g. Griffiths 2001).

Nevertheless there are reasons why vegetation and its component species may not be related to soil type. For example, within the one climatic zone, changes in microclimate due to altitude, aspect and the presence of 'frost hollows' could be associated with a change in vegetation. Diagrammatic cross sections showing changes in vegetation with slope, aspect and altitude suggest an independence between soils and vegetation. However, this is not always the case. Moore's (1953) Figure 9 indicates changes in dominant trees with increasing altitude and on different aspects in hilly country in the south-east Riverina but also indicates commensurate changes in the degree of soil development at different altitudes and aspects.

Major changes in vegetation and/or floristic assemblages across climatic zones, e.g. Prober & Thiele (2004) in NSW, and between widely separated areas within the temperate zone (e.g. south-western Western Australia v. south-eastern NSW) also suggest an independence of soils and vegetation – unless of course, soils also change across these distances. The main issue here is species availability. Even within the one climatic zone, propagules of some species are not available to all soils that could support that species. For example, *Eucalyptus albens*[1*], which occurs on a range of soil types, has disjunct populations across its southern range, particularly in Victoria and South Australia, though they may have been continuous in the past.

At the specific site level, the association between vegetation and soil (as well as topography, microclimate, etc.) is unique but this is not what is meant when it is asserted that soils and vegetation are closely associated. The latter implies that when 'soils' and 'vegetation' are classified in some way, then 'soil group A' is consistently associated with 'vegetation group X'. The nature of the relationship may be very specific, i.e. that A and X always occur together and never with other groups; but looser associations are also implied, e.g. that soil A is associated with vegetation X in some (perhaps climatic) areas but with Y in others. To test the strength of these associations in any particular region it is necessary to classify the soils and vegetation but soils and vegetation (and component plants) can be classified in a variety of ways and associations may be stronger with some classifications than with others.

One of the broadest taxonomic units used in soil mapping is the soil landscape, ".. *a characteristic landform pattern with one or more soil taxonomic units occurring in a related sequence. It is often associated with the physiographic features of the landscape…*" (Chapman & Atkinson 2000, p. 111). Hence, the area encompassed by any one soil landscape commonly contains more than one soil type. An additional source of heterogeneity in some soil landscapes is the presence of defined sub-units such as drainage lines. Heterogeneity is further increased in practice because small areas of soil landscapes within larger areas of another cannot be shown at small mapping scales such as 1: 250 000.

At a finer scale, soil types are groups of soils that have one or more properties in common. Depending on the perceived importance of individual soil properties and their location within the soil profile, a soil can be classified in a number of ways. In the field survey described below, three standard classifications were used: Great Soil Groups (Stace *et al.* 1968), the Australian Soil Classification (Isbell 1996) and Principal Profile Forms (Northcote 1979), as well as groups of the latter as described by Northcote *et al.* (1975). As these generalist classifications may not reflect local conditions, soils described in the survey were also grouped using a local classification devised by one of the authors [BWM].

Vegetation can be classified in a multitude of ways and formalised systems of doing so have (as with soils) changed over the years. No one system is universally adopted by vegetation surveyors but one based on structure and dominant or diagnostic species as described by Walker and Hopkins (1990) has general acceptance. Local classifications based on presence/absence or abundance of individual species can be generated using cluster analysis. Both methods of classification were used in the survey.

To adequately test the hypothesis that 'soils' and 'vegetation' are closely associated in the field , it is necessary to limit the role of non-soil factors likely to influence the composition of vegetation, i.e. organism-availability, time since disturbance, climate and topography. This can be done by selecting a relatively small area in which organism-availability and climate are likely to be uniform, where remnant vegetation in good condition is present, where changes in topography and relief are low, and where soils are known to vary widely. Maps of woody vegetation can be used to locate potentially useful stands of native vegetation; and soil landscape maps can be used to assess likely soil variability.

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[*] Botanic nomenclature follows that of Wheeler et al. (2002), Harden (1990–93) and subsequent usage by the Royal Botanic Gardens Sydney.

Four hypotheses, from the general to the specific, were tested:

1. Soil landscapes are consistently associated with particular vegetation types.
2. Soil types are consistently associated with particular vegetation types.
3. Soil types are consistently associated with presence/absence of plant species.
4. Soil properties (pH, colour, structure, etc.) are consistently associated with the presence/absence of plant species.

Methods

Site selection

Maps of remnant woody vegetation (Ritman 1995; Sivertsen and Metcalfe 1995) and soil landscapes (King 1998; Andersson and McNamara, unpublished) in the area covered by the Forbes and northern Cootamundra 1: 250 000 map sheets were examined for suitable sites. Following a reconnaissance survey, a ~16 km section of a ~60 m wide Travelling Stock Reserve, Driftway Road, south of the Mid-Western Highway and about 30 km west of Grenfell, NSW (lat 33° 55'S, long 147° 45'E) (Fig. 1) was selected for a detailed study of soils and vegetation. The area has low relief and a subhumid climate (mean annual rainfall at Grenfell of ~ 630 mm) with slight winter dominance. Vegetation had been mapped as box (*Eucalyptus* spp.) woodland, *Callitris glaucophylla* woodland and non-woody. Soils mapping indicated four different soil landscapes suggesting a wide range of soil types. Three of the soil landscapes, 'Caragabal', 'Marsden' and 'Wah Way', occurred on level

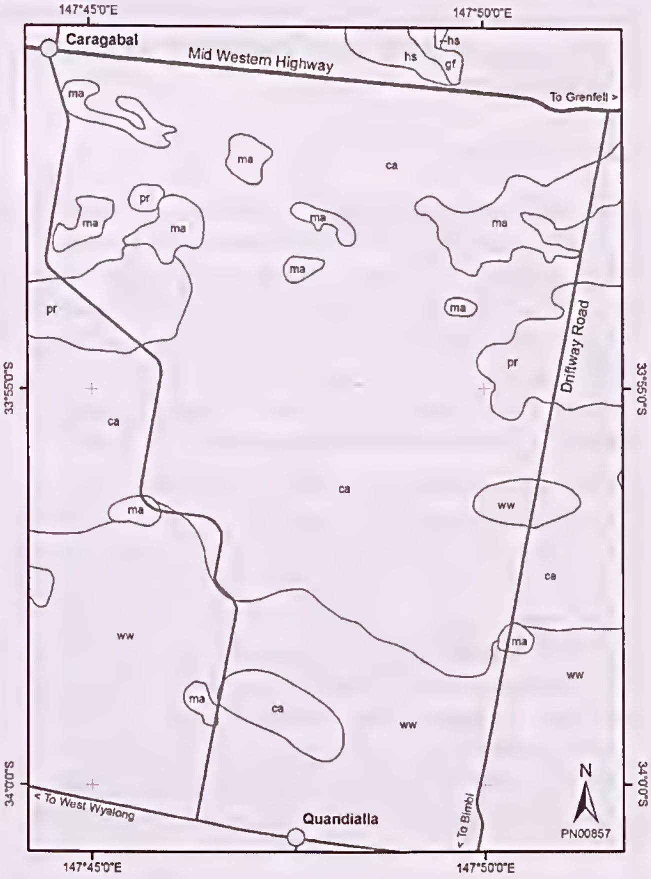

Fig. 1. The study area west of Grenfell, NSW, showing soil landscapes [King (1998), Anderrson & McNamara (unpublished)] along Driftway Road: Caragabal (ca), Marsden (ma), Piney Range (pr) and Wah Way (ww).

Table 1. Sub-units and soil types of the soil landscapes sampled on the Forbes and Cootamundra 1: 250 000 map sheets. Adapted from King (1998), Andersson and McNamara (unpublished).

Soil landscape	**Defined units within landscape**	**Defined inclusions of other soil landscapes within mapped area**	**Main soil types (Great Soil Groups)**
Caragabal (ca)	Plains, low rises with sandy topsoils, drainage depressions.	'Wah Way' on less elevated plains with heavy soils. 'Marsden' on areas gilgai.	Red-brown earth & red solodic (plains); red earth (upper plains); brown clay with (lower plains); red solodic (depressions).
Marsden (ma)	Gilgai crests, depressions.	'Wah Way' on areas without gilgai.	Red, grey & brown clays; occasional humic gley.
Piney Range (pr)	Crests, midslopes, lower slopes, drainage lines.	'Ironbarks' on larger ridges and crests.	Lithosol (crests); non-calcic brown, red earth & red podzolic (mid and lower slopes); red-brown earth & red solodic (lower slopes and drainage lines).
Narraburra (nr)	Plains, sand ridges, drainage depressions, prior streams.	'Marsden' on areas with gilgai. 'Cypress Park'.	Red-brown earth, non-calcic brown, red clay, soloth (plains); red podzolic (prior stream crests).
Wah Way (ww)	Plains, flooded areas.	'Barmedman Creek', 'Caragabal' & 'Marsden'.	Red, grey & brown clays; red- brown earth; non-calcic brown; red podsolic.

terrain whereas 'Piney Range' was on slightly undulating terrain with a maximum relief of ~10 m along the transect. The soil landscapes, together with an unmapped outlier of 'Narraburra' that was discovered during the survey, are described in Table 1.

Survey procedures

Pre-determined sampling points – specified distances along the road – were located within but not near the boundary of each of the four mapped soil landscapes such that each would be sampled eight times. At each point, the sampling site was located 25 m to the east of the road and pegged. If this site was unsuitable, e.g. due to disturbances such as tracks or gravel extraction or was in some way atypical, a location 50 m further south along the road was selected.

With the peg as centre, a 20 x 20 m plot with one side parallel to the road was laid out. Cover-abundance of all ground-storey species was assessed using a 0 to 7 Braun-Blanquet scale similar to that described by French *et al.* (2000). Ground-storey species identification was facilitated by the absence of grazing in the months prior to the survey in May 2000. Immature annual plants that could not be identified at the time were recorded as 'annual herbage' (subsequently found to contain up to 13 species, mainly grasses). As a number of common species, especially perennial grasses, lacked flowers/seedheads, all sites were revisited in spring 2000 to update species identifications.

Numbers of individuals of low shrubs (all *Maireana microphylla*) were counted within each plot. Since other woody species (potential mature height >1.5 m) were often infrequent in the plots, their numbers were determined within a circular plot of 25 m radius, centred on the plot peg. These data were converted to numbers of plants per hectare. Woody species present nearby but not within plots were recorded as a 'marginal occurrence'.

The soil profile at the peg (the centre of the plot) was examined to a depth of ~1 m using a 75 mm diameter soil auger. Soil horizons and terrain features were described. Samples from each horizon were collected and later assessed for field texture, $pH_{1:5\ soil:water}$ and electrical conductivity ($EC_{1:5\ soil:water}$) using the same procedures as described for King's (1998) soil landscapes survey. All data were recorded on standard Soils Data System Cards and subsequently entered on the SALIS database (Milford *et al.* 2001).

Classification of soils and vegetation at each site

Soils and vegetation were described independently. Classification of soils at each site and determination of the site's match with the mapped soil landscape (or another soil landscape) were carried out by BWM. Species determination and tree/shrub density measurements were carried out by MOR and WSS, who also determined the initial vegetation classification based on structural formation, dominant species and understorey type (grassy v. shrubby). They also considered the vegetation at each site in terms of 'density/floristic indices', which included the number of native ground-storey species, number of native woody species, number of all native species and densities of native woody plants.

Alternative classifications of the vegetation at each site were generated from floristic data by TBK using an agglomerative numerical hierarchical cluster analysis (HCA) within Belbin's (1995) PATN software package. The analysis was performed on three data sets: (a) densities of individual woody species, (b) Braun-Blanquet values for ground-storey species and (c) presence/absence data for all species. Of the 122 species recorded in the plots, 24 were excluded because they occurred at only one site. The choice of an acceptable number of groups from the HCA was made by examination of a scree diagram (Krzanowski 1990). This graphical plot displays the declining within-group variance against an increasing number of groups. Typically, the formation of the first few groups shows a sharp decline in average within-group variance, followed by a much more gradual rate of decrease. The number of 'principal' groups formed by the analysis is suggested to be near the point of inflection of this curve, since the cost of further increases in the group complexity of the system comes at only marginal benefits in reduction of within-group variance.

Hypothesis testing

To test hypothesis (1), that soil landscapes are consistently associated with particular vegetation types, it was necessary to ascertain that each site visited in the field actually fitted the description of the soil landscape within which it was mapped; i.e. that the site was not located on an unusual sub-unit or on a small outlier of another soil landscape, or that the mapping was incorrect. This was done by comparing terrain and soils at the site with those described for the soil landscape. If a discrepancy occurred, the site was reallocated to a more appropriate soil landscape category. Hence, hypothesis (1) was tested at two levels: (a) for soil landscapes as shown on the map and (b) for soil landscapes as amended following field evaluation.

To test for associations, separate two-way tables for each of the four vegetation classifications versus each of the soil landscapes (as originally mapped and as amended) were prepared and examined using a range of measures of association: Cramer's V^2, Somer's D, Goodman-Kruskal gamma and Kendall's tau-b (Minitab 2005). Differences between mean density/floristic indices for each group of sites (i.e. according to soil landscape as mapped or as amended) were assessed using analysis of variance.

Hypothesis (2), that soil types are consistently associated with particular vegetation types, was tested for each of the five soil classifications using the same procedures as described above.

Only the local soil classification was used to test hypothesis (3), that soil types are associated with the presence/absence

Table 2. Soil variables and soil horizons – A (a), upper B (b) and lower B (bb) unless otherwise indicated – that were used in the Canonical Correspondence Analysis of soil properties and the occurrence of plant species.

Ranges of each variable across horizons are shown in parentheses. Symbols for each soil variable are given in bold. [A] Derived from texture and structure (after Williams *et al.* 1983). [B] Laboratory ($pH_{1:5\ soil:water}$) test results only

Colour	Physical	Inclusions	Chemistry
H Hue (10–17.5)	**LD** Lower depth of horizon (5–80 cm)	**CFN** Coarse fragments (nil – abundant)	**EC** $EC_{1:5\ soil:water}$ (0.03–1.0 dS/m)
V Value (3–5)	**TN1** Texture (fine sandy loam – medium clay)	**CCNbb** Calcium carbonate segregations [lower B only] (nil – many)	**pHR** pH (Field Raupach) (5.0–9.0)
Ch Chroma (2–8)	**TN2** Water holding capacity at field capacity [A] (80–260 mm /m of soil)	**Rock** Rock at depth [lower B only] (yes/no)	**pHW** $pH_{1:5\ soil:water}$ (4.63–9.27)
M Munsell colour (very pale brown – dark red)	**StN** Structure grade (weak – strong)		**pHb–a** pH [B] trend [upper B minus A] (-0.61–1.87)
			pHbb–b pH [B] trend [lower B minus upper B] (-0.05–2.45)

of one or more plant species. Site species lists were grouped according to soil types to determine species that were restricted to particular types.

As soil properties and species are narrowly-defined, hypothesis (4), that soil properties are consistently associated with the presence/absence of one or more plant species, did not require multiple testing. The test was limited to 40 soil x horizon properties (Table 2) extracted from the soil profile data at each site. The interaction between these soil variables and species, as measured by the presence/absence for all species that occurred more than once at each site, was examined using Canonical Correspondence Analysis (CCA) (ter Braak 1987).

Results

Twenty nine field sites were described. Sampling of the Marsden soil landscape was less frequent than desired – five sites instead of eight – because of the need to avoid soil landscape boundaries. Examination of soils and terrain at each of the sites indicated that six sites mapped as Wah Way did not fit the general description of that soil landscape. Five of these sites were re-allocated to Caragabal (a reported inclusion in Wah Way soil landscape; Table 1) and the other to Narraburra. Soil landscapes, soil types, vegetation types and vegetation indices at each site are presented in Appendix 1.

Depending on the classifications employed, soils at the 29 sites encompassed: six groups in the local classification (see Table 3), six Great Soil Groups, seven Principal Profile Form (PPF) groups (representing eight PPFs) or eight groups in the Australian Soil Classification.

Five vegetation types were identified in the field: (a) inland grey box – white cypress pine (*Eucalyptus microcarpa – Callitris glaucophylla*) grassy woodland (3 sites), (b) open grassy woodland (15 sites), (c) inland grey box – white cypress pine shrubby woodland (5 sites), (d) belah (*Casuarina cristata*) forest (3 sites) and (e) natural grassland (3 sites). These five groups were subsequently reduced to four by abandoning the distinction between woodlands and open woodlands as the difference between the two may be an artefact of human activity.

Pattern analysis of tree and shrub density data yielded four groups plus a group lacking trees and shrubs (aA to aE in Appendix 1). Ground-storey Braun-Blanquet data yielded six groups (bA to bF in Appendix 1). Presence/absence data yielded three groups (cA to cC in Appendix 1).

Table 3. Soil types in the local classification

A:	Brown clays on alluvium ('Caragabal soil')
B.	Well-drained massive earths on metasediments ('Piney Range soil')
C.	Grey cracking clays on alluvium ('Wah Way soil')
D.	Red duplex soil on prior stream deposits ('Narraburra soil')
E.	Grey cracking clay with gilgai on alluvium ('Marsden soil')
F.	Deep, brown soils on colluvium. Includes duplex soils and massive earths. Transitional between soils A and B.

Twenty eight tree and tall shrub species were recorded. Of these, seven occurred outside the plots and five occurred at only one site. *Maireana microphylla* was the only low shrub recorded in any quantity. *Eucalyptus microcarpa* (at 26 sites) and *Maireana microphylla* (22 sites) were the most frequent woody species. Apart from some annual exotic grasses and forbs ('annual herbage') that were not identifiable in autumn 2000, 101 herbaceous and subshrub species were recorded. Of these, 19 were recorded at only one site. Species and their frequency of occurrence on soils of the local classification are listed in Appendix 2.

Associations between soil landscapes and vegetation types or indices

Measures of association between vegetation types (in the various classifications) and soil landscapes, as originally mapped or after amendment, were low. This indicated that none of the vegetation types was solely associated with a particular landscape and conversely, that no soil landscape (except those with very few sites) was solely associated with a particular vegetation type. An example is presented in Table 4.

Significant differences ($P<0.05$) were evident between some soil landscapes and density/floristic indices, particularly those related to woody plants. Piney Range and Wah Way (together with Narraburra, which was represented by only one site) represented the two extremes of tree/tall shrub density in this survey. Sites within Piney Range landscape had a significantly higher mean number of woody native species (7.5) and mean density of native tree/tall shrubs (1293 plants/ha) but a lower mean number of ground-storey species (17.6) than the other soil landscapes. In contrast, sites within Wah Way landscape had a low mean density of tree/tall shrubs (132 or 156 plants/ha depending on whether the calculation was based on the original or amended mapping) and the highest mean number of ground-storey species (26.9 or 33.5).

Table 4. The occurrence of four conventionally-classified vegetation types at sites within Caragabal (ca), Marsden (ma), Piney Range (pr), Wah Way (ww) and Narraburra (nr) soil landscapes. All measures of association between this (and other) vegetation classifications and soil landscapes were low.

Numbers indicate the number of sites with that vegetation – soil landscape combination.

	Sites classified according to mapped soil landscapes				Sites reclassified into more appropriate soil landscapes				
	ca n=8	ma n=5	pr n=8	ww n=8	ca n=13	ma n=5	pr n=8	ww n=2	nr n=1
Grassy woodland	7	2	4	5	9	2	4	2	1
Shrubby woodland	1	0	4	0	1	0	4	0	0
Belah forest	0	3	0	0	0	3	0	0	0
Grassland	0	0	0	3	3	0	0	0	0

Table 5. The occurrence of vegetation types (for two of the four vegetation classifications) at sites classified according to Principal Profile Form soil groups.

Numbers in each cell indicate the number of sites with that vegetation – soil combination.
BDS= Brown duplex soil; RDS= Red duplex soil; YDS=Yellow duplex soil; RME =Red massive earth;
BME =Brown massive earth; RSE= Red structured earth; GCC= Grey massive cracking clay.

Vegetation classification	BDS n=7	RDS n=1	YDS n=1	RME n=10	BME n=3	RSE n=1	GCC n=6
(a) PATN vegetation classification based on presence/absence data for all species. Somer's D and Goodman-Kruskal gamma measures of association were relatively high at –0.7 and –0.8 respectively for this combination of vegetation type and soil type.							
Vegetation type cA	1	1	1	10	3	1	2
Vegetation type cB	2	0	0	0	0	0	2
Vegetation type cC	4	0	0	0	0	0	2
(b) A conventional classification based on structure, dominant species/species groups. Somer's D and Goodman-Kruskal gamma measures of association were relatively low at 0.4 and 0.5 respectively for this combination of vegetation type and soil type.							
Grassy woodland	5	0	1	6	3	1	2
Shrubby woodland	0	1	0	4	0	0	0
Belah forest	1	0	0	0	0	0	2
Grassland	1	0	0	0	0	0	2

Associations between soil types and vegetation types or indices

An association between one of the PATN vegetation classifications and Principal Profile Form soil groups was relatively high but unique combinations of soil type and vegetation type were absent. Though five of the seven PPF groups were associated with only one vegetation type, it was the same type for all five (Table 5a). Measures of association between other vegetation classifications and soil classifications were generally low (e.g. Table 5b).

No significant differences between sites on the one soil type and mean numbers of ground-storey species were evident. However, mean numbers of woody species were significantly lower on clay soil types and higher on soil B ('Piney Range soil') than on the other soil types. Mean densities of low shrub also varied significantly between some soil types, e.g. being higher on red earths than on red brown earths.

Associations between soil types of the local classification and plant species

Examination of species occurrence on soil types A to F (Table 3) indicated that species fell into three broad groups. The first comprised relatively common species that occurred on virtually all soil types. e.g. *Austrodanthonia setacea* (26 sites), *Enteropogon acicularis* (26 sites), *Oxalis* sp. (26 sites), *Vittadinia* sp. (23 sites), *Austrostipa aristiglumis* (14 sites) and *Austrostipa blackii* (17 sites) though no single species was recorded on all sites. *Eucalyptus microcarpa* (26 sites) and *Einadia nutans* (25 sites) occurred on all but soil type C. A second group comprised rare species that occurred at only

Table 6. Native species occurring on ≥ 3 sites (or 2 sites for species restricted to Soil C) that occurred *only* on one or two soil types of the local classification.
Numbers indicate the number of sites within each soil type where the species was recorded. Data from Appendix 2.

Species symbol	Species	Soil F	Soil B	Soil C	Soil D	Soil E	Soil A
		9 Sites	11	2	1	4	2
	Group 1						
Bchd	*Brachyscome heterodonta*	3					
Cbnl	*Cymbonotus lawsonianus*	3					
Maen	*Maireana enchylaenoides*	3					
Pltq	*Plantago drummondii*	6					
Madc	*Maireana decalvans*	4			1		
	Group 2A						
Alom	*Allocasuarina luehmannii*	4	3				
Pspp	*Pittosporum phylliraeoides*	6	8				
Emdb	*Eremophila debilis*	3	3				
Akol	*Acacia oswaldii*	3	2				
Chlz	*Cheilanthes* sp.	1	8				
Ahpi	*Arthropodium minus*	2	2				
Lazz	*Lomandra* sp.	3	4				
Einh	*Einadia hastata*	1	4				
Sieg	*Austrostipa elegantissima*	3	4				
	Group 2B						
Mpmt	*Myoporum montanum*		8				
Bhkz	*Bothriochloa macra/decipiens*		3				
	Group 3A						
Klop	*Calostemma purpureum*	2		1			
Erjp	*Eryngium plantagineum*	3		2			
Sspc	*Swainsona procumbens*	2		2			
	Group 3B						
Ixll	*Ixiolaena leptolepis*			2			
Lymh	*Lythrum hyssopifolia*			2			
Rnzz	*Ranunculus* sp.			2			
Eezb	*Eleocharis* sp. 'b'			2			
	Group 4						
Kzct	*Casuarina cristata*	2				2	
Dpkf	*Diplachne fusca*	2				2	
Fbdk	*Fimbristylis dicotoma*	1				2	
	Group 5						
Akmv	*Acacia melvillei*					3	1
Srcr	*Sporobolus caroli*					3	2

one or two sites – perhaps by chance and about which little can be interpreted. The remaining group, comprising species which were neither rare nor widespread, were examined for consistent associations with one or two soil types. As shown in Table 6, two relatively common species, *Plantago drummondii* and *Myoporum montanum*, were recorded only on the one soil type – F and B respectively. Also evident was a number of species assemblages that were associated with one or two soil types, e.g. group 2A, where the woody plants, *Allocasuarina luehmannii*, *Pittosporum phylliraeoides*, *Acacia oswaldii* and (sub-shrub) *Eremophila debilis*, together with a number of forbs, were associated with soils F and B.

Associations between soil properties and plant species

An indication of the soil properties associated with each of the species groups shown in Table 6 can be obtained from the CCA analysis of the presence/absence of all species (Fig. 2). Vectors representing the measured soil properties showed a distinct 'left-right' contrast in the first two axes (Fig. 2a), with the higher values of pH, electrical conductivity (EC), texture (TN1 and TN2) and structure (StN) to the left; and higher values of coarse fragments (CFN), horizon depth (LD) and most attributes of colour (Ch, H, M) to the right. Further insight into the dominant associations between soil variables can be made from the plot of the 1st and 3rd axes from the CCA analysis (Fig. 2c). Horizon depth (LD) lifts

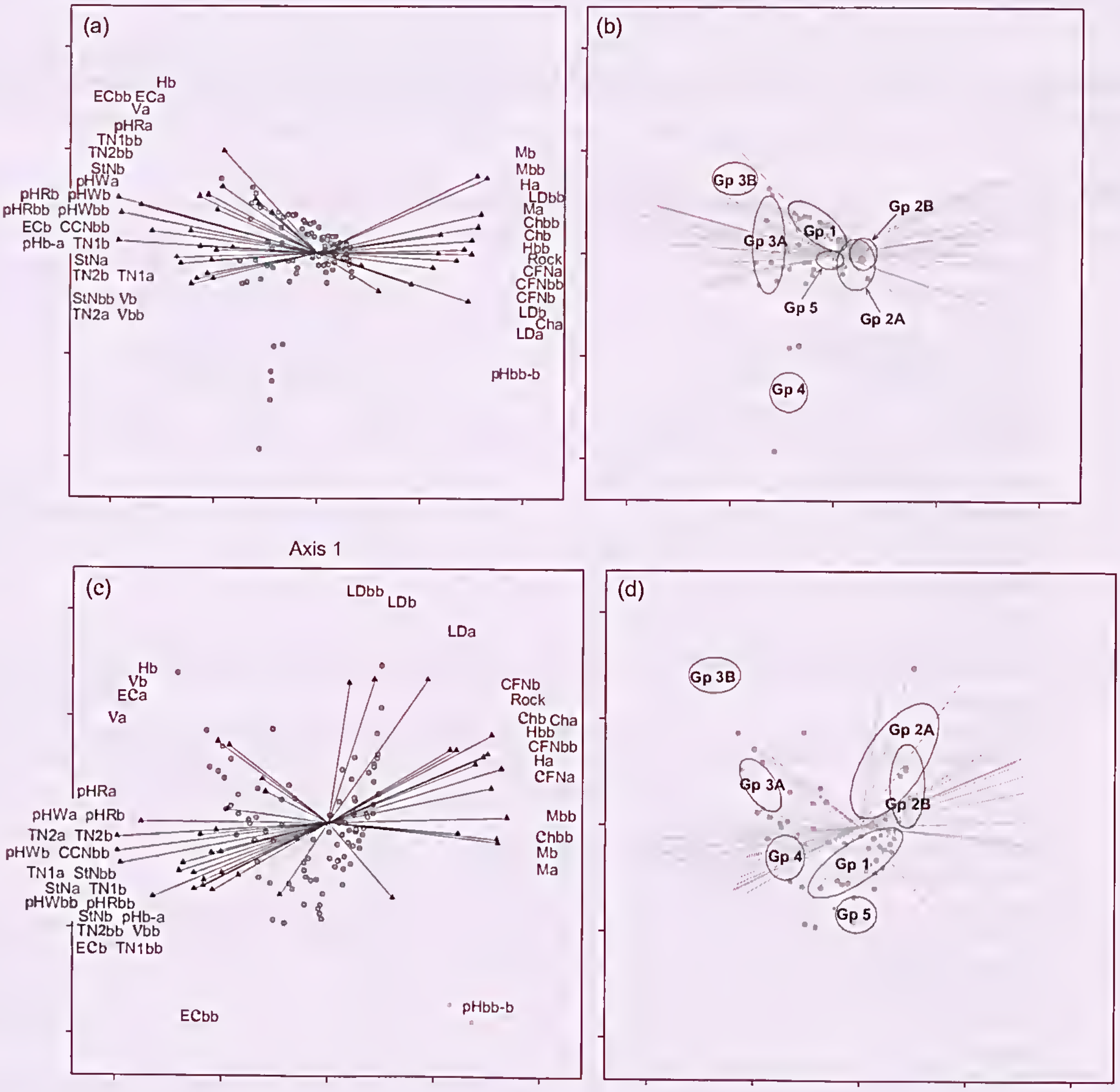

Fig. 2. Biplots of the 1st and 2nd axes [(a) and (b)] and 1st and 3rd axes [(c) and (d)] from Canonical Correspondence Analysis of the presence/absence of species using soil properties as a set of supplementary variables. To aid interpretation, contrasts between soil properties are displayed in the left hand panels, while differences between species groups are shown in the right hand panels. All spatial coordinates are from the one analysis. Species are shown as dots and groups of dots (see Table 6) and soil properties in three horizons, a, b and bb, as vectors (see Table 2 for key to symbols).

itself 'upwards' from other soil variables above the plane of axes 1 and 2, contrasting with EC in the lower B horizon (ECbb) and change in pH within the B horizon (pHbb–b), which 'fall away' below the plane of the 1st and 2nd axes.

Most species were clustered near the centroid of the plot of the 1st and 2nd axes (Figs. 2a & b), but showed additional separation along the 3rd dimension (Figs. 2c & d). Amongst these were species within groups 1 and 5 (which were associated with increasing pH in the B horizon and higher EC in the lower B horizon) and group 2, which tended to be associated with deeper (high LD values), gravelly (high CFN values) soils with low pH and coarser textures (low TN1 values). However, species within groups 3A, 3B and 4 were clearly segregated. Group 4 (*Casuarina cristata, Diplachne fusca* and *Fimbristylis dichotoma*) was associated with well-structured (high StN values), gravel-free (low CFN values) soils of fine texture (high TN1 values) in all horizons and soil colour (low Ch, V and H). Group 3A (*Calostemma purpureum, Eryngium plantagineum* and *Swainsona procumbens*) was broadly associated with higher EC (though none of the soils sampled was saline), high pH and fine textures throughout the profile. While having similar soil associations to group 3A, the unique set of species of group 3B (Table 6) was strongly associated with higher EC in the A horizon and colour (high H and V) of the upper soil horizons.

Discussion

Hypothesis 1. Soil landscapes are consistently associated with particular vegetation types

Regardless of whether individual sites represented mapped or amended soil landscapes, all measures of association between landscapes and vegetation types were low as exemplified by the data presented in Table 4. Nevertheless some vegetation types occurred only on a single soil landscape, e.g., belah forests occurred only on Marsden and natural grasslands only on Wah Way (as mapped) or Caragabal (as amended). Grassy woodlands of Inland Grey Box – White Cypress Pine occurred on all soil landscapes.

Associations between density/floristic indices and soil landscapes indicated that, on average, sites on Piney Range had significantly higher diversity and density of native tree/shrubs but lower diversity of ground-storey species than the other landscapes. Whether 'woodiness' was primarily associated with soils in the strict sense or with the slightly undulating topography or metasediment parent material on this landscape is debatable. On the other hand, sites on Wah Way had a significantly lower average tree/shrub density and a higher average number of ground-storey species. Similar differences between numbers of native shrub and low tree species (from 2 to 33) on some soil landscapes in the Bathurst area (Semple 1997) suggests that soil landscapes may have some predictive power with respect to 'woodiness'.

To what extent then can a soil landscape map be used to predict vegetation types? In terms of 'conventional' vegetation types (Table 4), any one of the sampled landscapes would be expected to support inland Grey Box – White Cypress Pine grassy woodlands whereas shrubby woodlands and higher numbers of white cypress pine would be more likely on Piney Range. On land mapped as Marsden, belah open forest would also be expected to occur; and on Wah Way, grasslands. In the latter case, however, all the grasslands occurred on small inclusions of the Caragabal landscape so, in practice, grasslands would also be expected to occur on areas mapped as Caragabal.

Although there was sometimes an association, albeit not exclusive, between some soil landscapes and some vegetation types, these could be predicted prior to a field survey. Hence, to use soil landscapes as surrogates for vegetation would in most cases lead to error in this study area.

Hypothesis 2. Soil types are consistently associated with particular vegetation types

If consistent associations between soil types and vegetation types exist then they should have been apparent from the soils and vegetation data collected. Up to eight soil types and up to six vegetation types were represented in the survey. However, association measures between all combinations were generally low apart from that presented in Table 5a. As with soil landscapes, there were no unique combinations of soil and vegetation type (apart from one-off occurrences of soil types) and no vegetation type was restricted to one soil type. The data therefore indicated that a vegetation type can occur on a number of soil types and that a soil type (apart from those that were recorded infrequently) can support a number of vegetation types. However, the red massive earth (RME) and brown massive earth (BME) soil types were exceptions in that they were associated with only one vegetation type (Table 5a) or in the case of the RME, two closely-related types (Table 5b) – albeit one(s) that occurred on other soil types. Some density/floristic indices yielded closer associations with specific soil types, e.g. clayey soil types were associated with low diversity and often low density of woody plants.

To what extent then can knowledge of a soil type be used to predict the occurrence of vegetation types? For the soils encountered in this survey (and ignoring those which occurred infrequently), it may be predicted that all of them are likely to be associated with one vegetation type (e.g. type cA or grassy/shrubby woodlands in Table 5) but that some (BDS and GCC) are likely to be associated with other vegetation types as well. Even though environmental variability within a soil type may be expected to be much lower than within a soil landscape, this answer is very similar to that provided for soil landscapes.

It is well known that any one vegetation type can occur across a variety of soil types (e.g. the *Eucalyptus albens* alliance;

Moore 1953) but the corollary, that the one soil type can support, or is associated with, a variety of vegetation types, in not always appreciated. The results from this survey clearly show this to be the case and there is no reason to suppose that the study area is unique in this respect. The failure to appreciate this relationship may be a consequence, at least partly, of the way vegetation types are often described in terms of their associated soils in vegetation surveys, e.g. *Austrostipa aristiglumis* grassland with dark grey self-mulching clays (Biddiscombe 1963) and *Acacia pendula* woodlands with grey clays (Sivertsen & Metcalfe (1995). Such descriptions *imply* that the vegetation type always occurs on the stated soil type and that the soil type always supports the specified vegetation type. Though this may be the case for the two examples cited, it is not general.

The issue of associations between soils and vegetation types is further complicated by the nature of classification itself. Soils and vegetation at any one site are essentially unique and classifying them on the basis of pH, depth, etc. (for soils) or tallest species, most common species, etc. (for vegetation) is largely based on convenience, which may or may not have relevance to the properties that affect plant growth (for soil classifications) or the habitat requirements of the dominant species, in the case of vegetation classifications. As a 'vegetation type' is basically an assemblage of species, it seems unreasonable to expect soil types to be associated primarily with the dominant(s), particularly one like *Eucalyptus microcarpa*, which appears to be suited to a wide range of environments.

Hypothesis 3. Soil types are consistently associated with the presence/absence of plant species

Six species, including *Austrodanthonia setacea* and *Enteropogon acicularis*, occurred on all soil types sampled (though not at all sites) but some groups of species were apparently restricted on one or two soil types (Table 6) and others, though occurring on most soil types, were absent from one or two. For example, *Eucalyptus microcarpa, Maireana microphylla, Elymus scaber, Calotis lappulacea, Atriplex spinibractea, Atriplex semibaccata, Einadia nutans, Sclerolaena muricata, Dichondra repens* and *Goodenia pinnatifida* occurred on all soil types except type C – albeit represented at only two sites. This suggests that knowledge of soil types may have some predictive value for presence/absence of some species (though little can be said about species or soil types recorded infrequently in this survey).

Hypothesis 4. Soil properties (pH, colour, structure, etc.) are consistently associated with the presence/absence of plant species

A Canonical Correspondence Analysis of species presence/absence and soil properties (Fig. 2) suggested that some species with restricted distributions were associated with a suite of soil properties. For example, species in group 4 (*Casuarina cristata, Diplachne fusca* and *Fimbistylis dicotoma*) were associated with well structured, gravel-free soils with finer than average texture. However, the associations suggested should be considered tentative as they were based on only a few occurrences of these species and more sites would need to be described to increase confidence.

Conclusions

Soil landscape maps could not be used as surrogate vegetation maps though, if supplemented by local knowledge, some soil landscapes may be helpful in locating specific vegetation types. In the case of soil types that were encountered more than once, none was uniquely associated with a particular vegetation type. The most common vegetation type, a grassy woodland, occurred on all soil types whereas others, e.g. belah forest, occurred on two soil types only. Although some soils were associated with only the most common vegetation type, most supported more than one vegetation type.

However, there were significant associations between aspects of woodiness and some soil landscapes (e.g. high density and numbers of species of woody plants on the Piney Range soil landscape) and some soil types (e.g. low numbers of woody species on clay soil types). Although many plant species occurred on virtually all soil types encountered, some were apparently restricted to one or two – presumably in response to a suite of soil properties that were incompletely defined in this study.

Though apparently unique associations of vegetation types and soil types have been reported in other vegetation surveys, they were not evident in this study, though soils were examined in more detail than would probably be the case for most vegetation surveys. In an earlier and much larger study where soils were examined in considerable detail, Beadle (1948) concluded that associations between soils and vegetation were very ill-defined. The results of our survey support this. We do not deny that such associations do occur in some instances but we also note that some vegetation surveyors are not prepared to make definitive statements about vegetation and soil types except in a general way. For example, Westbrooke and Miller (1995) and Tozer (2003) emphasise geomorphology or geology, and Stafford and Eldridge (2000) emphasise soil properties.

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Appendix 1. Characteristics of sites (grouped according to soil landscapes as originally mapped).

[A] GW *E. microcarpa – C. glaucophylla* grassy woodland; SW *E. microcarpa – C. glaucophylla* shrubby woodland; BF *C. cristata* open forest; G natural grassland
[B] RD Red Dermosol; BD Brown Dermosol; GD Grey Dermosol ; GV Grey Vertosol; RC Red Chromosol; BC Brown Chromosol; RK Red Kandosol; BK Brown Kandosol.
[C] Db1.13 Brown duplex soil (BDS); Dr2.13 Red duplex soil (RDS); Dy2.13 Yellow duplex soil (YDS): Gn2.12 & Gn2.13 Red massive earth (RME); Gn2.43 Brown massive earth (BME); Gn4.13 Red structured earth (RSE); Ug5.5 Grey massive cracking clay (GCC).
[D] BC Brown clay; GC Grey clay; RBE Red-brown earth; BE Brown earth; RE Red earth; YS Yellow solodic.
[E] See Table 3.

Site number	**1**	**2**	**6**	**7**	**16**	**17**	**20**	**21**	**3**	**4**	**5**	**22**	**23**
Soil landscapes													
As mapped	ca	ca	ca	ca	ca	ca	ca	ca	ma	ma	ma	ma	ma
After amendment	ca	ca	ca	ca	ca	ca	ca	ca	ma	ma	ma	ma	ma
Floristic indices – numbers of native species within:													
(a) ground-storey	32	29	23	22	20	8	30	12	24	24	17	10	18
(b) trees	1	3	1	1	3	3	2	3	2	2	4	2	2
(c) shrubs	1	1	2	3	6	1	5	2	1	2	0	0	0
(d) low shrub	1	1	1	1	1	0	0	1	1	1	1	0	0
(e) trees, shrubs & low shrubs	3	5	4	5	10	4	7	6	4	5	5	2	2
(f) site (i.e. all species)	35	34	27	27	30	12	37	18	28	29	22	12	20
Density (plants/ha) of:													
(a) native low shrub, *Maireana microphylla*	150	150	1375	1725	150	0	0	50	225	750	25	0	0
(b) native trees & shrubs	46	97	102	168	772	244	341	922	173	112	825	1268	703
Vegetation types:													
Conventional [A]	GW	GW	GW	GW	SW	GW	GW	GW	GW	GW	BF	BF	BF
PATN a	aA	aA	aB	aB	aB	aB	aB	aB	aA	aA	aD	aD	aD
PATN b	bA	bA	bA	bA	bB	bF	bA	bB	bA	bA	bC	bC	bC
PATN c	cA	cA	cA	cA	cA	cB	cC	cA	cA	cA	cB	cB	cB
Soil types:													
Aust. Soil Classification [B]	GV	BD	RD	RD	RC	RC	BC	BC	GD	GV	GV	BC	GV
Principal Profile Forms (PPFs)	Ug 5.5	Db 1.13	Gn 4.13	Gn 2.13	Dr 2.13	Db 1.13	Db 1.13	Gn 2.43	Dy 2.13	Ug 5.5	Ug 5.5	Db 1.13	Ug 5.5
PPF groups [C]	GCC	BDS	RSE	RME	RDS	BDS	BDS	BME	YDS	GCC	GCC	BDS	GCC
Great Soil Groups [D]	BC	RBE	RE	RE	RBE	RBE	RBE	RE	YS	GC	GC	RBE	GC
Local classification [E]	A	A	B	B	B	F	F	F	E	E	E	F	E

Site number	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**18**	**19**	**24**	**25**	**26**	**27**	**27**	**29**
Soil Landscapes																
As mapped	pr	pr	pr	pr	pr	pr	pr	pr	ww	ww	ww	ww	ww	ww	ww	ww
After amendment	pr	pr	pr	pr	pr	pr	pr	pr	ww	ww	ca	ca	ca	ca	ca	nr
Floristic indices – numbers of native species within:																
(a) ground-storey	20	17	20	20	15	18	14	17	34	33	19	21	29	25	34	20
(b) trees	3	3	2	3	3	3	2	3	1	2	3	2	0	0	0	2
(c) shrubs	3	3	5	1	3	4	4	7	5	3	4	1	0	0	0	1
(d) low shrub	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1
(c) trees, shrubs & low shrubs	7	7	8	5	7	8	7	11	7	6	8	4	0	0	0	4
(d) site (i.e. all species)	27	24	28	25	22	26	21	28	41	39	27	25	29	25	34	24
Density (plants/ha) of:																
(a) native low shrub, *Maireana microphylla*	1825	650	1450	200	75	875	50	175	25	50	325	325	0	0	0	1900
(b) native trees & shrubs	581	382	550	148	1397	2063	2241	2980	224	87	581	97	0	0	0	56
Vegetation types:																
Conventional [A]	GW	GW	GW	GW	SW	SW	SW	SW	GW	GW	GW	GW	G	G	G	GW
PATN a	aB	aB	aB	aB	aC	aC	aC	aC	aA	aA	aB	aA	aE	aE	aE	aA
PATN b	bA	bA	bA	bA	bA	bA	bB	bB	bD	bD	bA	bA	bE	bE	bD	bA
PATN c	cA	cA	cA	cA	cA	cA	cA	cA	cC	cC	cA	cA	cC	cC	cC	cA
Soil types:																
Aust. Soil Classification [B]	RD	RD	RD	RD	RK	RD	RD	RK	RC	BC	BK	BD	GV	GV	BC	RD
Principal Profile Forms (PPF)	Gn	Gn	Gn	Gn	Gn	Gn	Gn	Gn	Db	Db	Gn	Gn	Ug	Ug	Db	Gn
	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.12	1.13	1.13	2.43	2.43	5.5	5.5	1.13	2.13
PPF groups [C]	RME	RME	RME	RME	RME	RME	RME	RME	BDS	BDS	BME	BME	GCC	GCC	BDS	RME
Great Soil Groups [D]	RE	RE	RE	RE	RE	RE	RE	RE	RBE	RBE	BE	BE	GC	GC	RBE	RE
Local classification [E]	B	B	B	B	B	B	B	B	F	F	F	F	C	C	F	D

Appendix 2. Frequency of occurrence on sites with the same soil type in the local classification of vascular plant species recorded along Driftway Road during 2000.

Species are flowering plants except conifers (marked A) or (ferns (B). Tree/shrub species marked # were not recorded in plots but were noted nearby ('marginal occurrences') or in the general area. * = introduced species. # = a 'marginal occurrence', i.e. a tree/shrub species noted in the area but not recorded in plots.

§ = a group comprising one or more of the following species: **Avena* sp., **Bromus diandrus*, **Bromus molliformis*, **Hordeum leporinum*, **Hordeum hystrix*, **Lolium rigidum* & **Vulpia bromoides* (Poaceae), **Arctotheca calendula* (Asteraceae), **Echium plantagineum* (Boraginaceae), **Capsella bursa-pastoris* (Brassicaceae), **Medicago* & **Trifolium* spp. (Fabaceae), **Parentucellia latifolia* (Scrophulariaceae).

		Soil types (see Table 3)						
Trees (family minus -aceae)	Species	F 9 sites	A 2 sites	B 11 sites	C 2 sites	D 1 sites	E 4 sites	all soils 29 sites
Cupress	*Callitris glaucophylla* [A]	3	0	9	0	1	0	14
Casuarin	*Allocasuarina luehmannii*	4	0	3	0	0	0	7
Casuarin	*Casuarina cristata*	2	0	0	0	0	2	4
Fab	*Acacia melvillei*	0	1	0	0	0	3	4
Fab	*Acacia pendula* #							
Myopor	*Myoporum platycarpum* #							
Myrt	*Eucalyptus albens*	0	0	1	0	0	0	1
Myrt	*Eucalyptus conica* #							
Myrt	*Eucalyptus melliodora* #							
Myrt	*Eucalyptus microcarpa*	8	2	11	0	1	4	26
Rut	*Geijera parviflora*	0	0	1	0	0	0	1
Sapind	*Alectryon oleifolius*	1	1	2	0	0	1	5
Tall shrubs								
Aster	*Cassinia laevis*	1	0	1	0	0	0	2
Fab	*Acacia acinacea*	0	0	1	0	0	0	1
Fab	*Acacia deanei* #							
Fab	*Acacia difformis*	0	0	1	0	0	0	1
Fab	*Acacia hakeoides*	4	0	5	0	1	2	12
Fab	*Acacia lineata*	0	0	2	0	0	0	2
Fab	*Acacia oswaldii*	3	0	2	0	0	0	5
Fab	*Acacia trineura*	2	0	0	0	0	0	2
Fab	*Senna artemisioides*	2	1	9	0	0	1	13
Myopor	*Myoporum montanum*	0	0	8	0	0	0	8
Pittospor	*Pittosporum phylliraeoides*	6	0	8	0	0	0	14
Prote	*Hakea* sp. #							
Santal	*Santalum acuminatum* #							
Sapind	*Dodonaea viscosa* ssp. *cuneata*	3	1	4	0	0	0	8
Solan	**Lycium ferocissimum*	0	0	0	0	0	1	1
Low shrubs								
Chenopodi	*Maireana microphylla*	5	2	11	0	1	3	22
Total number of tree/shrub/low shrub species recorded within plots		**13**	**6**	**17**	**0**	**4**	**8**	**21**
Total number of ex-plot tree/shrub/low shrub species								*7*
Ground-storey								
Marsile	*Marsilea sp.* [B]	2	1	0	2	0	2	7
Sinopterid	*Cheilanthes* sp. [B]	1	0	8	0	0	0	9
Amaryllid	*Calostemma purpureum*	2	0	0	1	0	0	3
Antheric	*Arthropodium minus*	2	0	2	0	0	0	4
Colchic	*Wurmbea dioica*	2	0	0	0	0	0	2
Cyper	*Carex inversa*	3	0	1	2	0	1	7
Cyper	*Eleocharis* sp. 'a'	0	0	0	1	0	0	1
Cyper	*Eleocharis* sp. 'b'	0	0	0	2	0	0	2
Cyper	*Fimbristylis dichotoma*	1	0	0	0	0	2	3
Irid	**Romulea* sp.	1	0	0	0	0	0	1
Junc	*Juncus* sp. 'a'	3	0	0	2	0	2	7

		F	A	B	C	D	E	all soils
		9 sites	2 sites	11 sites	2 sites	1 sites	4 sites	29 sites
Junc	*Juncus* sp. 'b'	0	0	0	0	0	1	1
Lomandr	*Lomandra* sp.	3	0	4	0	0	0	7
Orchid	*?Pterostylis* sp.	0	0	1	0	0	0	1
Po	Austrodanthonia caespitosa	8	0	2	2	1	1	14
Po	*Austrodanthonia setacea*	8	2	11	1	1	3	26
Po	*Austrostipa aristiglumis*	3	2	3	2	1	3	14
Po	*Austrostipa blackii*	5	2	6	1	1	2	17
Po	*Austrostipa elegantissima*	3	0	4	0	0	0	7
Po	*Austrostipa nodosa*	4	1	3	0	0	1	9
Po	*Austrostipa scabra*	2	0	10	0	1	0	13
Po	*Bothriochloa macra/decipiens*	0	0	3	0	0	0	3
Po	*Chloris truncata*	3	1	1	1	0	0	6
Po	*Diplachne fusca*	2	0	0	0	0	2	4
Po	*Elymus scaber*	6	1	5	0	1	1	14
Po	*Enteropogon acicularis*	8	2	10	1	1	4	26
Po	*Eragrostis* sp.	1	0	0	0	0	1	2
Po	*Eriochloa pseudoacrotricha*	5	1	0	2	0	1	8
Po	*Panicum decompositum*	1	0	0	0	0	0	1
Po	*Panicum simile*	1	1	0	0	0	0	2
Po	*Paspalidium constrictum*	1	2	1	0	0	0	4
Po	**Paspalum dilatatum*	0	0	0	1	0	0	1
Po	**Phalaris paradoxa*	0	0	0	1	0	1	2
Po	*Sporobolus caroli*	0	2	0	0	0	3	5
Po	*Walwhalleya proluta ined.*	2	0	0	2	0	2	6
Amaranth	*Alternanthera denticulata*	1	1	0	1	0	1	4
Amaranth	*Ptilotus obovatus* var. *parviflorus*	2	1	0	0	0	2	5
Api	*?Trachymene* sp.	1	0	0	1	0	0	2
Api	*Eryngium plantagineum*	3	0	0	2	0	0	5
Aster	Brachyscome ciliaris	3	2	1	0	0	0	6
Aster	*Brachyscome heterodonta*	3	0	0	0	0	0	3
Aster	*Calocephalus* sp.	0	1	0	0	0	1	2
Aster	*Calotis anthemoides*	1	0	0	0	0	0	1
Aster	*Calotis cuneifolia*	3	0	9	0	1	0	13
Aster	*Calotis lappulacea*	2	1	7	0	1	1	12
Aster	*Calotis scabiosifolia*	0	0	0	2	0	1	3
Aster	**Carthamus lanatus*	2	0	0	0	0	0	2
Aster	*Cymbonotus lawsonianus*	3	0	0	0	0	0	3
Aster	*Eclipta platyglossa*	0	0	0	1	0	0	1
Aster	*Hedypnois rhagodioloides*	1	0	0	0	0	0	1
Aster	*Isoetopsis graminifolia*	1	0	0	0	0	0	1
Aster	*Ixiolaena leptolepis*	0	0	0	2	0	0	2
Aster	*Ixiolaena tomentosa*	0	0	0	1	0	0	1
Aster	*Minuria integerrima*	1	0	0	0	0	1	2
Aster	*Podospermum resedifolium*	1	0	0	1	1	0	3
Aster	*Pycnosorus chrysanthus*	4	0	0	2	0	1	7
Aster	*Rhodanthe corymbiflora*	1	2	0	0	0	1	4
Aster	*Solenogyne bellioides*	0	0	1	0	0	0	1
Aster	**Sonchus oleraceus*	0	0	2	2	0	1	5
Aster	*Triptilodiscus pygmaeus*	1	0	0	0	0	0	1
Aster	*Vittadinia* sp. [*V. gracilis*?]	7	2	10	1	1	3	24
Brassic	**Lepidium africanum*	2	0	2	0	0	2	6
Campanul	*Wahlenbergia* spp.	4	2	6	0	0	1	13
Caryophyll	**Spergularia rubra*	3	2	0	0	0	1	6
Chenopodi	*Atriplex semibaccata*	2	2	5	0	1	3	13
Chenopodi	*Atriplex spinibractea*	1	2	7	0	1	2	13
Chenopodi	*Chenopodium desertorum*	1	0	7	0	0	2	10
Chenopodi	*Einadia hastata*	1	0	4	0	0	0	5
Chenopodi	*Einadia nutans*	7	2	11	0	1	4	25
Chenopodi	*Enchylaena tomentosa*	0	2	8	0	0	3	13
Chenopodi	*Maireana decalvans*	4	0	0	0	1	0	5
Chenopodi	*Maireana enchylaenoides*	3	0	0	0	0	0	3
Chenopodi	*Maireana humillima*	0	0	1	0	0	0	1
Chenopodi	*Salsola kali*	1	2	4	0	0	0	7

		F **9 sites**	**A** **2 sites**	**B** **11 sites**	**C** **2 sites**	**D** **1 sites**	**E** **4 sites**	**all soils** **29 sites**
Chenopodi	*Sclerolaena brachyptera*	0	0	0	0	0	1	1
Chenopodi	*Sclerolaena muricata*	1	2	4	0	1	3	11
Chenopodi	*Sclerolaena stelligera*	1	0	0	0	0	0	1
Convolvul	*Convolvulus erubescens*	3	2	2	1	0	2	10
Convolvul	*Dichondra repens*	4	2	8	0	1	2	17
Crassul	*Crassula* sp.	1	0	0	0	0	0	1
Euphorbi	*Chamaesyce drummondii*	3	2	1	1	0	1	8
Fab	*Glycine* sp.	1	1	1	0	0	0	3
Fab	*Swainsona procumbens*	2	0	0	2	0	0	4
Goodeni	*Goodenia* spp.	1	0	1	1	0	0	3
Goodeni	*Goodenia pinnatifida*	4	2	10	0	1	2	19
Lami	**Marrubium vulgare*	0	0	6	0	1	1	8
Lami	**Salvia verbenaca*	0	0	4	0	0	0	4
Lami	*Teucrium racemosum*	1	0	0	0	0	0	1
Lin	*Linum marginale*	1	0	0	1	0	0	2
Lobeli	*Pratia concolor*	0	0	0	2	0	2	4
Lythr	*Lythrum hyssopifolia*	0	0	0	2	0	0	2
Malv	*Sida corrugata*	2	2	7	0	0	2	13
Malv	*Sida cunninghamii*	4	2	0	1	0	3	10
Myopora	*Eremophila debilis*	3	0	3	0	0	0	6
Oxalid	*Oxalis* sp.	8	2	10	2	1	3	26
Plantagin	*Plantago drummondii*	6	0	0	0	0	0	6
Polygon	*Rumex tenax*	3	2	1	1	1	2	10
Ranuncul	*Ranunculus* sp.	0	0	0	2	0	0	2
Rubi	*Asperula cunninghamii*	4	1	0	2	0	0	7
Scrophulari	*Mimulus gracilis*	1	0	0	0	0	0	1
Solan	*Solanum esuriale*	3	1	2	0	0	1	7
Total number of ground-storey species		**78**	**38**	**47**	**39**	**21**	**49**	**101**
'Annual herbage'[§]		9	11	1	1	1	4	28

Vegetation of Imbota and Yina Nature Reserves, Armidale, New South Wales

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Abstract: The vegetation of Imbota Nature Reserve (30° 35'S, 151° 45'E) (218 ha in area), 10 km south-east of Armidale, and Yina Nature Reserve (30° 29'S, 151° 45'E), (101 ha in area), 10 km east of Armidale, on the Northern Tablelands, NSW, is described. Based on classification analyses, air photo interpretation and ground-truthing, seven vegetation communities are described and mapped :

1. *Eucalyptus caliginosa* (Broad-leaved Stringybark) Grassy Forest and Woodland on deep soils at Imbota
2. *Eucalyptus viminalis* (Manna Gum) Grassy Forest and Woodland, Community
3. *Eucalyptus caliginosa* (Broad-leaved Stringybark) Grassy Forest and Woodland on shallow soils at Imbota
4. *Eucalyptus caliginosa* (Broad-leaved Stringybark) Grassy Forest and Woodland at Yina
5. *Eucalyptus blakelyi* (Blakely's Red Gum) – *Eucalyptus melliodora* (Yellow Box) Woodland
6. *Eucalyptus viminalis* (Manna Gum) – *Eucalyptus nova-anglica* (New England Peppermint) Grassy Forest and Woodland
7. Riparian Herbfields

252 vascular plant taxa (from 59 families) were recorded from the two reserves, 179 species in Imbota NR, the larger reserve and 209 in Yina NR. The lower species richness at Imbota is likely to have resulted human disturbance rather than from overall habitat heterogeneity.

***Cunninghamia* (2007) 10(2): 215–224**

Introduction

Imbota Nature Reserve (30° 35'S, 151° 45'E) and Yina Nature Reserve (30° 29'S, 151° 45E') lie 10 km to the south-east and 10 km to the east of Armidale respectively (Fig. 1). Both are in the Armidale/Dumaresq Shire and in the New South Wales Northern Tablelands Botanical District. Imbota includes 218 ha of remnant native vegetation and Yina, 101 ha.

The reserves were dedicated in 1999, prior to which Imbota NR was Eastwood State Forest and Yina NR was Hillgrove State Forest. Selective logging of hardwoods occurred in these forests from the 1920s onwards but this was sporadic. Timber was regularly removed for firewood and fence posts, and domestic stock grazed the areas up until the reserves were gazetted in 1999. The reserves are currently bordered on all sides by private holdings and much of the surrounding lands are cleared and used for grazing (Fig. 2).

Imbota Nature Reserve includes a minor ridge, and ranges in elevation from 980 m to 1050 m. Some ill-defined drainage lines occur but no definitive creeks flow through the reserve. Rock types include greywacke, slate, chert, jasper, metabasalt, phyllite and schist. The soils are of lithosols or low nutrient sandy soils.

Yina Nature Reserve includes a minor ridge with primarily north-east facing slopes of elevation ranging from 960 m to 1030 m. The eastern boundary is marked by Burying Ground Creek, a minor tributary of the Commissioners Waters, that eventually flows into the Gara River and the eastern fall of the Divide. The rock type of the reserve is mainly of metasediments and soils are generally lithosols or low nutrient sandy soils.

This paper gives part of the results of flora surveys carried out for the New England Tablelands Region of the NSW National Parks and Wildlife Service, to be used to develop appropriate management strategies (Hunter 2003ab).

Methods

Twenty-two quadrats, each 20 x 20 m, were surveyed for vascular plants scored using the Braun-Blanquet (1982) six point cover abundance scale within Imbota Nature Reserve, and a further 20 within Yina Nature Reserve. Quadrats were placed using a stratified random method. As only a small number of sites were available and the size of the reserve was small, physiography alone was used for site stratification. The 42 sites were surveyed over four days during March of 2003.

Voucher specimens were retained by the New England Tablelands Region of the NSW National Parks and Wildlife Service. Nomenclature follows that of Harden (1990–1993) except where recent changes have been made.

Analysis and data exploration were performed using options available in the PATN Analysis Package (Belbin 1995a, b). For final presentation of results all species and their cover abundance scores were used. Cluster analysis was performed using Kulczynski association measure, which is recommended for ecological applications (Belbin 1995a, b) along flexible Unweighted Pair Group arithmetic Averaging (UPGMA) and the default PATN settings.

Delineation of community boundaries in was based on the location of sites and their position within the multivariate analysis, air photograph interpretation, substrate and ground truthing. The vegetation map is based on a 1:25 000 scale. Structural names are based on the most consistent uppermost stratum.

Coleman curves (species accumulation) were calculated using EstimateS (Colwell 1997) for Imbota and Yina Nature Reserves and two other nearby reserves of small size Yarrowyck and Indawarra Nature Reserves (Hunter, unpublished data) for comparison of species turnover and species pool size.

Results

Within Imbota Nature Reserve 179 vascular plant taxa (from 55 families and 132 genera) were recorded from existing records and current sampling. Approximately 11% were of taxa introduced to NSW. The families with the highest number of taxa include: Poaceae (30), Asteraceae (28), Fabaceae (17), Cyperaceae (7), Rubiaceae (6) and Myrtaceae (5), Juncaceae (5) and Rosaceae (5).

Within Yina Nature Reserve 209 vascular plant taxa (from 56 families and 149 genera) were recorded. Approximately 20% were of taxa introduced to NSW. In total 252 vascular plant taxa (from 59 families) were found in the two reserves.

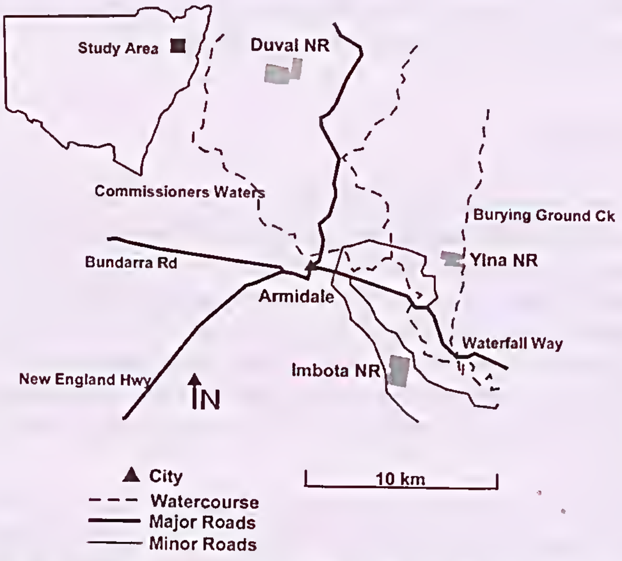

Fig. 1. Locality of Imbota and Yina Nature Reserves, east of Armidale, in the NSW Northern Tablelands

Vegetation communities

Seven vegetation communities are recognised at the dissimilarity of 0.6 (see dendrogram Figure 5). The mapped assemblages for Yina are shown in Figure 3 and Imbota in Figure 4. The structure of all communities was of forest or woodland formation although grasslands are found in areas that have been cleared and are yet to regenerate. In the following descriptions species from each layer are listed in order of decreasing importance (cover-abundance x frequency). Exotic species are not listed, their occurrence in each community is listed in Appendix 1.

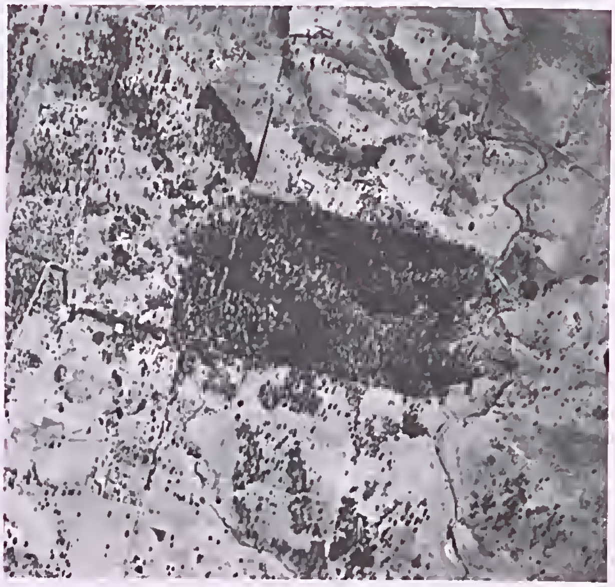

Fig. 2. Yina Nature Reserve is a 101 ha remnant within an extensively cleared landscape on the Northern Tablelands of NSW.

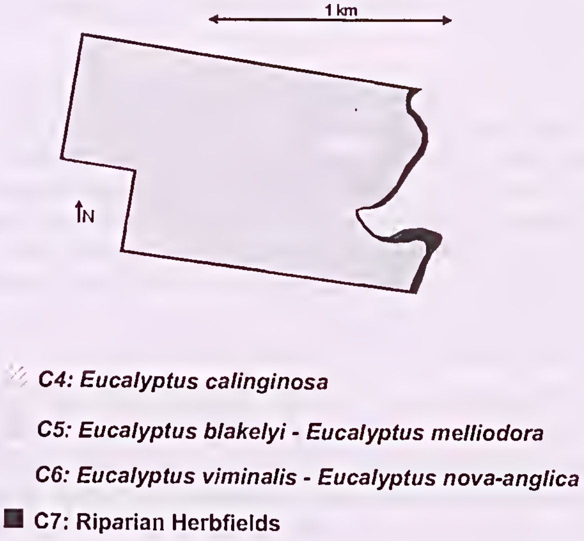
1 km
N
▨ C4: *Eucalyptus calinginosa*
C5: *Eucalyptus blakelyi - Eucalyptus melliodora*
C6: *Eucalyptus viminalis - Eucalyptus nova-anglica*
■ C7: Riparian Herbfields

Fig. 3. Vegetation communities for Yina Nature Reserve

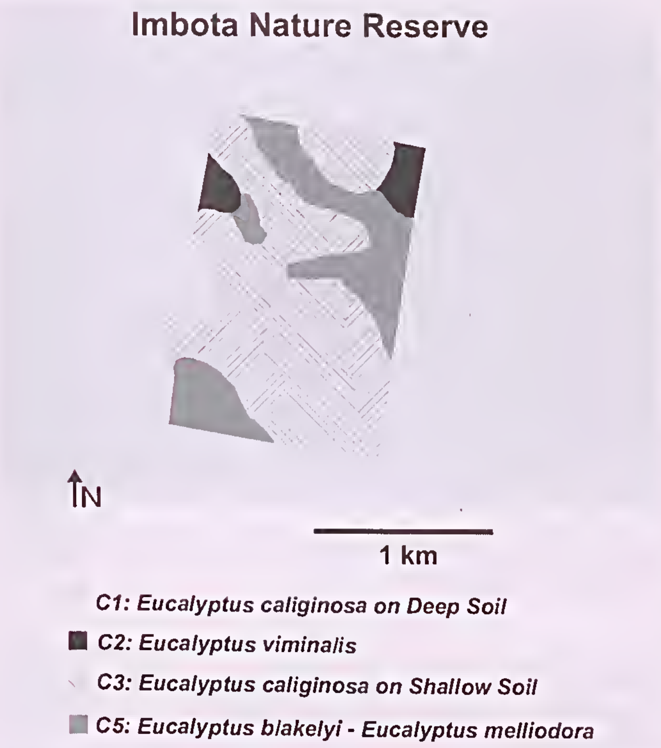
Imbota Nature Reserve
N
1 km
C1: Eucalyptus caliginosa on Deep Soil
■ C2: Eucalyptus viminalis
C3: Eucalyptus caliginosa on Shallow Soil
▒ C5: Eucalyptus blakelyi - Eucalyptus melliodora

Fig. 4. Vegetation communities for Imbota Nature Reserve

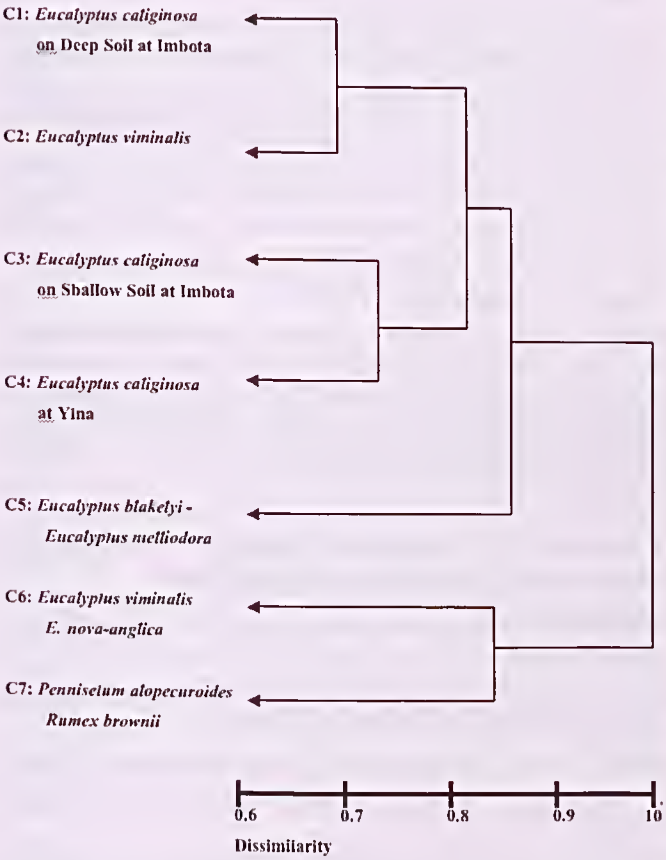
C1: Eucalyptus caliginosa on Deep Soil at Imbota
C2: Eucalyptus viminalis
C3: Eucalyptus caliginosa on Shallow Soil at Imbota
C4: Eucalyptus caliginosa at Yina
C5: Eucalyptus blakelyi - Eucalyptus melliodora
C6: Eucalyptus viminalis E. nova-anglica
C7: Pennisetum alopecuroides Rumex brownii
0.6
0.7
0.8
0.9
10
Dissimilarity

Fig. 5. Summary dendrogram of dataset of sites using Kulczynski association and flexible UPGMA fusion strategy. ommunities are defined at a dissociation of 0.6

Community 1: *Eucalyptus caliginosa* (Broad-leaved Stringybark) Grassy Forest and Woodland on deep soil at Imbota

Distribution: generally on hill slopes (Fig. 6).

Trees: *Eucalyptus caliginosa, Acacia filicifolia, Eucalyptus blakelyi, Eucalyptus melliodora, Eucalyptus viminalis, Eucalyptus bridgesiana, Allocasuarina littoralis.*

Shrubs: *Lissanthe strigosa, Olearia elliptica, Hibbertia obtusifolia, Einadia hastata, Brachyloma daphnoides, Olearia viscidula, Melichrus urceolatus, Jacksonia scoparia, Cassinia quinquefaria.*

Climbers & trailers: *Desmodium varians, Rubus parvifolius.*

Groundcover: *Dichondra repens, Microlaena stipoides, Poa sieberiana, Calotis cuneifolia, Oxalis chnoodes, Mentha diemenica, Echinopogon caespitosus, Hydrocotyle laxiflora, Cheilanthes sieberi, Rumex brownii, Eragrostis molybdea, Aristida ramosa, Themeda australis, Sporobolus elongatus, Lagenifera stipitata, Dichelachne micrantha, Opercularia diphylla, Lomandra multiflora, Austrostipa scabra, Austrodanthonia laevis, Wahlenbergia planiflora, Wahlenbergia luteola, Scleranthus biflorus, Plantago varia, Lomandra filiformis, Goodenia hederacea, Desmodium brachypodum, Carex inversa, Vittadinia muelleri, Viola betonicifolia, Urtica incisa, Senecio diaschides, Phyllanthus virgatus, Joycea pallida, Geranium solanderi, Fimbristylis dichotoma, Euchiton gymnocephalus, Dichanthium sericeum, Cyperus gracilis, Cymbopogon refractus, Cymbonotus lawsonianus, Chloris truncata, Austrodanthonia racemosa, Austrodanthonia pilosa, Austrodanthonia induta, Ajuga australis, Acaena novae-zelandiae.*

Number of taxa per plot: 33–(36)–41.

Notes: *Eucalyptus caliginosa* dominated assemblages are widespread throughout the central and eastern parts of the New England Tablelands and are one of the most highly conserved types. The major differences between community 1 and the following community 3 is the dominance of grasses and herbs in the ground layer with over 70% cover and comparatively scattered to non-existent shrub layer. These differences are likely due to the deeper and less rocky soils on which this assemblage is found.

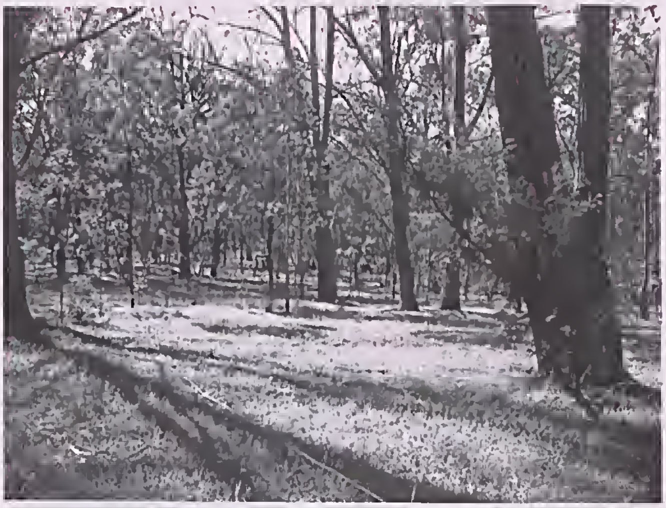

Fig. 6. Community 1: *Eucalyptus caliginosa* Forests and Woodlands in Imbota Nature Reserve on Deep Soils

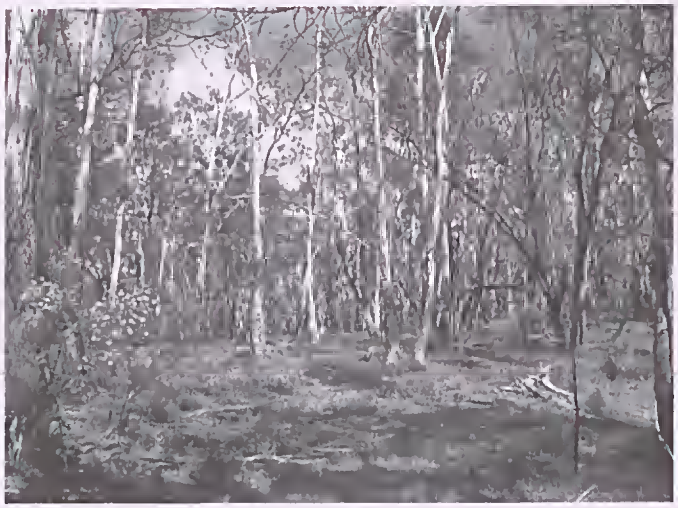

Fig. 7. Community 2: *Eucalyptus viminalis* Grassy Forest and Woodland

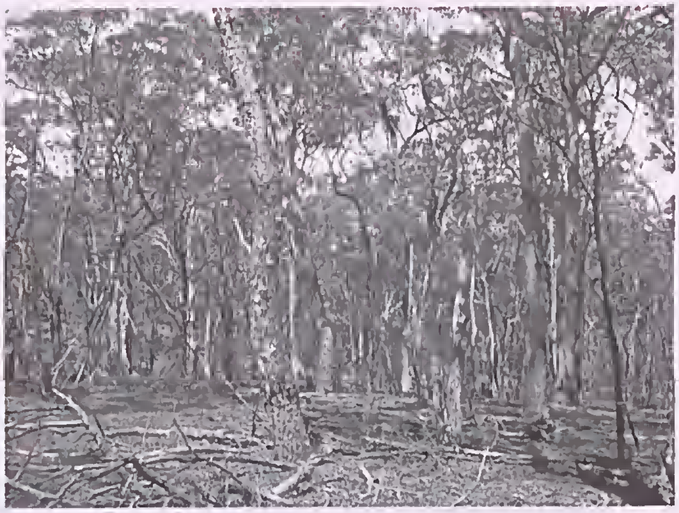

Fig. 8. Community 3: *Eucalyptus caliginosa* Grassy Forest and Woodland on Shallow Soil

Community 2: *Eucalyptus viminalis* (Manna Gum) Grassy Forest and Woodland

Distribution: restricted to low-lying valley bottoms and creek banks (Fig. 7).

Trees: *Eucalyptus viminalis, Acacia filicifolia, Eucalyptus bridgesiana, Eucalyptus caliginosa, Eucalyptus melliodora, Angophora floribunda, Eucalyptus blakelyi, Acacia implexa.*

Shrubs: *Lissanthe strigosa, Cassinia quinquefaria, Pultenaea microphylla, Olearia elliptica, Hibbertia obtusifolia, Pimelea curviflora, Melichrus urceolatus, Brachyloma daphnoides.*

Climbers & trailers: *Desmodium varians, Glycine tabacina, Glycine clandestina, Amyema pendulum.*

Groundcover: *Poa sieberiana, Themeda australis, Echinopogon caespitosus, Microlaena stipoides, Aristida ramosa, Dichondra repens, Mentha diemenica, Calotis cuneifolia, Dichelachne micrantha, Cheilanthes sieberi, Viola betonicifolia, Oxalis chnoodes, Goodenia hederacea, Hypericum gramineum, Hydrocotyle laxiflora, Desmodium brachypodum, Wahlenbergia luteola, Geranium solanderi, Opercularia diphylla, Austrodanthonia pilosa, Vernonia cinerea, Sporobolus elongatus, Austrodanthonia laevis, Ajuga australis, Vittadinia cuneata, Stackhousia viminea, Sorghum leiocladum, Senecio diaschides, Scleranthus biflorus, Phyllanthus virgatus, Lagenifera stipitata, Hypoxis hygrometrica, Fimbristylis dichotoma, Dichanthium sericeum, Cymbonotus lawsonianus, Asperula conferta, Veronica calycina, Solenogyne bellioides, Pomax umbellata, Plantago varia, Lomandra multiflora, Juncus filicaulis, Carex inversa, Austrostipa scabra, Acaena novae-zelandiae..*

Number of taxa per plot: 29–(38)-48.

Notes: *Eucalyptus viminalis* dominated assemblages are poorly reserved and have been heavily impacted upon throughout the region and are of high conservation concern. Within the Imbota Nature Reserve this community is largely of regrowth with few old trees.

Community 3: *Eucalyptus caliginosa* (Broad-leaved Stringybark) Grassy Forest and Woodland on shallow soil at Imbota

Distribution: found on shallow soils on ridge tops and in sheltered southern facing slopes (Fig. 8).

Trees: *Eucalyptus caliginosa, Acacia filicifolia, Eucalyptus blakelyi, Eucalyptus melliodora, Eucalyptus viminalis, Eucalyptus bridgesiana, Acacia implexa.*

Shrubs: *Einadia hastata, Cassinia quinquefaria, Olearia viscidula, Hibbertia obtusifolia, Lissanthe strigosa, Indigofera australis, Lotus cruentus.*

Climbers & trailers: *Desmodium varians, Glycine clandestina.*

Ground cover: *Dichondra repens, Dichelachne micrantha, Goodenia hederacea, Senecio diaschides, Calotis cuneifolia, Poa sieberiana, Lagenifera stipitata, Echinopogon caespitosus, Austrodanthonia laevis, Themeda australis, Scleranthus biflorus, Opercularia diphylla, Joycea pallida, Veronica calycina, Oxalis chnoodes, Microlaena stipoides, Wahlenbergia luteola, Lomandra multiflora, Gonocarpus teucrioides, Aristida ramosa, Rumex brownii, Wahlenbergia planiflora, Vittadinia cuneata, Desmodium brachypodum, Cyperus gracilis, Cheilanthes sieberi, Carex inversa, Ajuga australis.*

Number of taxa per plot: 26–(29)–33.

Notes: as with community 1, this assemblage is dominated by *Eucalyptus caliginosa* which is well reserved across its range. This community is generally separated from community 1 by the sparse ground layer which is often below 50% and a slightly greater representation of shrubs. These changes are likely due to the much shallower soils that often have outcropping surface rocks.

Community 4: *Eucalyptus caliginosa* (Broad-leaved Stringybark) Grassy Forest and Woodland

Distribution: generally on rocky ridges but also on shallower soil areas elsewhere (Fig. 9).

Trees: *Eucalyptus caliginosa, Acacia filicifolia, Eucalyptus blakelyi, Eucalyptus melliodora, Eucalyptus bridgesiana.*

Shrubs: *Pultenaea microphylla, Lissanthe strigosa, Hibbertia obtusifolia, Brachyloma daphnoides, Cassinia quinquefaria, Melichrus urceolatus, Indigofera australis.*

Climbers & trailers: *Desmodium varians, Glycine tabacina, Hardenbergia violacea, Glycine clandestina, Billardiera scandens.*

Groundcover: *Poa sieberiana, Aristida ramosa, Dichondra repens, Echinopogon caespitosus, Oxalis chnoodes, Opercularia diphylla, Goodenia bellidifolia, Wahlenbergia communis, Goodenia hederacea,*

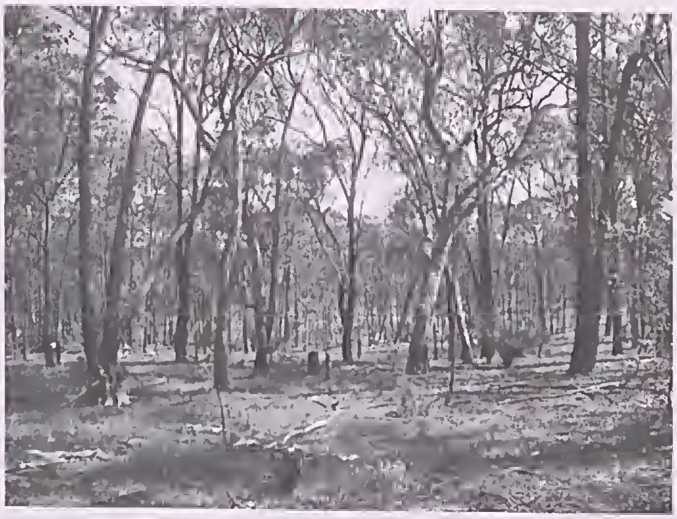

Fig. 9. Community 4: *Eucalyptus caliginosa* Forest and Woodland

Dichelachne micrantha, Themeda australis, Microlaena stipoides, Lagenifera stipitata, Joycea pallida, Senecio diaschides, Scleranthus biflorus, Einadia hastata, Ajuga australis, Viola betonicifolia, Lomandra longifolia, Lomandra filiformis, Hypericum gramineum, Geranium solanderi, Chrysocephalum apiculatum, Arthropodium milleflorum, Acaena novae-zelandiae.

Number of taxa per plot: 20–(34)–42.

Community 5: *Eucalyptus blakelyi* (Blakely's Red Gum) – *Eucalyptus melliodora* (Yellow Box) Woodlands

Distribution: restricted the lowest lying areas of the reserve along the most incised creek banks (Fig. 10).

Trees: *Eucalyptus blakelyi, Eucalyptus melliodora, Eucalyptus caliginosa, Acacia filicifolia, Eucalyptus bridgesiana, Acacia implexa, Eucalyptus viminalis.*

Shrubs: *Lissanthe strigosa, Cassinia quinquefaria, Pultenaea microphylla, Melichrus urceolatus, Lespedeza juncea.*

Climbers & trailers: *Desmodium varians, Glycine tabacina, Glycine clandestina.*

Groundcover: *Aristida ramosa, Poa sieberiana, Microlaena stipoides, Mentha diemenica, Dichondra repens, Fimbristylis dichotoma, Brachyscome heterodonta, Vittadinia muelleri, Sporobolus creber, Geranium solanderi, Cheilanthes sieberi, Oxalis chnoodes, Haloragis heterophylla, Dichelachne micrantha, Senecio diaschides, Chrysocephalum apiculatum, Bothriochloa decipiens, Viola betonicifolia, Phyllanthus virgatus, Lagenifera stipitata, Hypericum gramineum, Hydrocotyle laxiflora, Cymbonotus lawsonianus, Carex inversa, Sorghum leiocladum, Rumex brownii, Acaena novae-zelandiae, Hypoxis hygrometrica, Eragrostis molybdea, Echinopogon caespitosus, Austrodanthonia racemosa, Wahlenbergia communis, Themeda australis, Plantago varia, Plantago debilis, Cymbopogon refractus, Acaena ovina, Goodenia hederacea, Einadia hastata, Austrostipa scabra, Desmodium brachypodum, Ajuga australis..*

Number of taxa per plot: 34–(44)–59.

Notes: grassy *Eucalyptus blakelyi* and *Eucalyptus* melliodora associations of high conservation concern are poorly represented within the local and state reserve network. The areas in both Imbota and Yina Nature Reserves have been cleared, often heavily in the past, and as such few older trees remain and much of the community is of various stages of recovery.

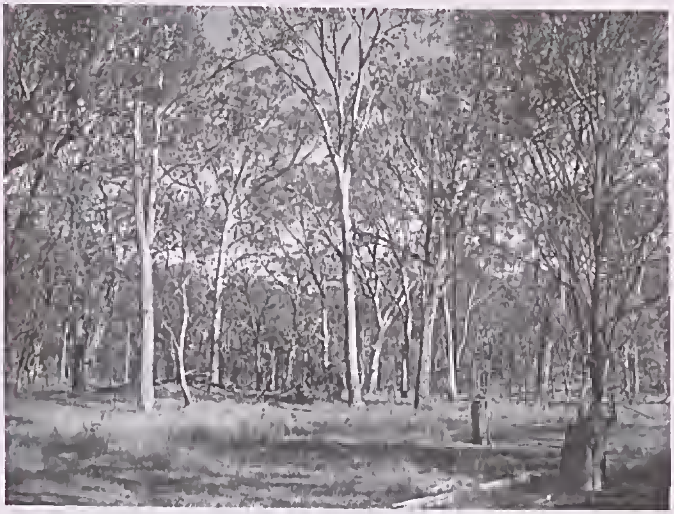

Fig. 10. Community 5: *Eucalyptus blakelyi – Eucalyptus melliodora* Grassy Forest and Woodland

Community 6: *Eucalyptus viminalis* (Manna Gum) – *Eucalyptus nova-anglica* (New England Peppermint) Grassy Forest and Woodland

Distribution: restricted to low-lying creek banks and alluvial flats (Fig. 11).

Trees: *Eucalyptus viminalis, Eucalyptus nova-anglica, Eucalyptus blakelyi.*

Shrubs: *Pimelea curviflora, Bursaria spinosa, Phyllanthus virgatus, Lissanthe strigosa, Lespedeza juncea.*

Climbers & trailers: *Desmodium varians, Glycine tabacina, Convolvulus erubescens.*

Groundcover: *Poa sieberiana, Sporobolus creber, Asperula conferta, Sorghum leiocladum, Fimbristylis dichotoma, Epilobium billardierianum, Rumex brownii, Hypericum gramineum, Bothriochloa bladhii, Chrysocephalum apiculatum, Pennisetum alopecuroides, Geranium solanderi, Eragrostis molybdea, Bothriochloa decipiens, Aristida ramosa, Viola hederacea, Microlaena stipoides, Mentha diemenica, Hypoxis hygrometrica, Hydrocotyle laxiflora, Acaena ovina,*

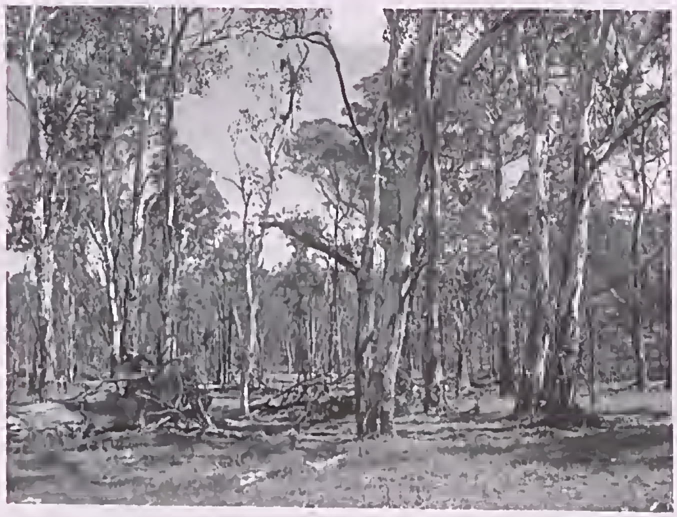

Fig. 11. Community 6: *Eucalyptus viminalis – Eucalyptus nova-anglica* Grassy Forest and Woodland

Acaena novae-zelandiae, Xerochrysum bracteatum, Wahlenbergia communis, Tricoryne elatior, Persicaria hydropiper, Oxalis chnoodes, Lagenifera stipitata, Isolepis gaudichaudiana, Haloragis heterophylla, Cyperus sphaeroideus, Austrodanthonia penicillata, Aristida vagans.

Number of taxa per plot: 25–(29)–32.

Notes: this community of high concern with very little found within conservation reserves. Community 6 was not found within Imbota Nature Reserve and was restricted to a very small area associated with the floodplain of Burying Ground Creek in Yina Nature Reserve.

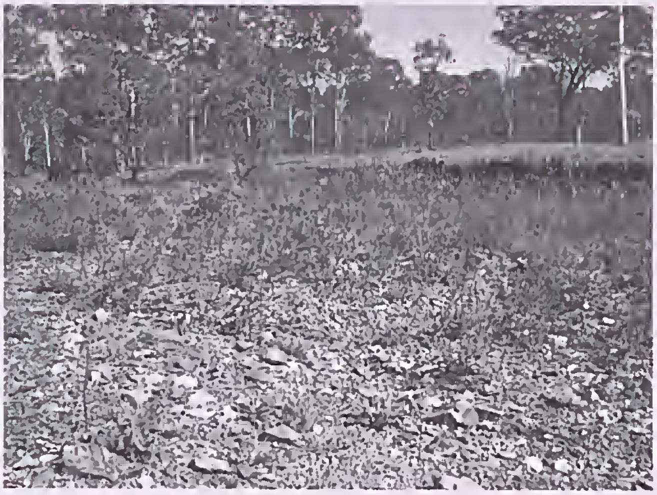

Fig. 12. Community 7: Riparian Herbfield

Community 7: *Pennisetum alopecuroides* (Swamp Foxtail) – *Rumex brownii* (Dock) Riparian Herbfields

Distribution: restricted riparian areas with occasional sparse trees (Fig. 12).

Trees: *Eucalyptus nova-anglica, Eucalyptus viminalis, Eucalyptus caliginosa, Eucalyptus blakelyi.*

Shrubs: *Lespedeza juncea, Callistemon sieberi.*

Climbers & trailers: *Glycine tabacina, Desmodium varians.*

Ground cover: *Pennisetum alopecuroides, Rumex brownii, Paspalum distichum, Eleocharis pallens, Sporobolus elongatus, Persicaria hydropiper, Geranium solanderi, Epilobium billardierianum, Typha orientalis, Stackhousia monogyna, Senecio bipinnatisectus, Scirpus polystachyus, Plectranthus graveolens, Lomandra longifolia, Leptocarpus tenax, Dichondra repens, Dichanthium sericeum, Cynoglossum australe, Cymbopogon refractus, Chamaesyce drummondii, Bothriochloa decipiens, Bothriochloa bladhii, Asperula conferta, Aristida ramosa, Acaena novae-zelandiae, Wahlenbergia communis, Rorippa laciniata, Pterostylis* sp., *Pratia pedunculata, Poa sieberiana, Microlaena stipoides, Juncus subsecundus, Juncus subglaucus, Cheilanthes sieberi, Ammobium alatum.*

Number of taxa per plot: 45–(47)–49.

Notes: this community is found on the banks of permanent creeks and was restricted to the eastern boundary of Yina Nature Reserve.

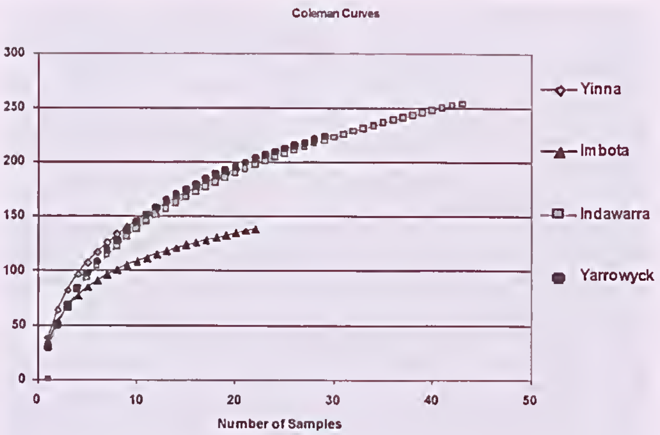

Fig 13. Coleman curves, showing smoothed species accumulation relationships based on 1000 permutations using EstimateS (Colwell 1997). Four small reserves all local to the Armidale area of the Northern Tablelands are compared. Note that Imbota is less diverse than the other three reserves in comparison.

Discussion

The vegetation communities of Imbota and Yina Nature Reserves are broadly similar to many found in the central parts of the NSW Northern Tablelands above 1000 m altitude. The distribution of the seven described assemblages is largely a reflection of topography and drainage.

Though the two reserves share the same rock type, altitude and similar vegetation, Imbota Nature Reserve, with 179 species recorded, is surprisingly poor in the number of species it contains. Yina Nature Reserve which is half the size and a more isolated remnant has more species (209), though the species richness per site is not significantly different (t-test 0.2243). Both reserves were surveyed by the same surveyor under the same intensity and within the same week of the same year.

A comparison of the turnover and overall species richness of the reserve compared to other small reserves in the area (Fig. 13) shows that Imbota has a much lower overall richness and although site richness is not significantly different, turnover certainly is. Thus compared to three other similarly-sized local reserves, Imbota has more uniform floristics between sites. These differences could be explained by the fact that it has less habitat heterogeneity than the three other reserves. For example Yina contains a well-defined watercourse (there is not one in Imbota), and Indawarra and Mt Yarrowyck Nature Reserves both incorporate greater elevation changes (400–500 m). Imbota has also had a greater human impact by the local Armidale community, as access is much easier and available from two public sealed roads on either side of the reserve, whereas access to Yina, Mt Yarrowyck and Indawarra requires access through private land on unsealed roads. Of these two factors, overall habitat heterogeneity and human disturbance, it is likely that the latter, human disturbance, has contributed the greater overall impact at Imbota, and resulted in the lower species richness and turnover.

Under previous management the reserve lands were regularly burnt, grazed and often used for local firewood collection. Only *Ozothamnus adnatus* in Imbota is listed as a significant species with RoTAP (Briggs & Leigh 1996) coding of 3RC– (Copeland & Hunter 1999). Though this species was not found during this investigation, it has been found opportunistically in the past. No listed rare or threatened species were found within Yina Nature Reserve. As this investigation was limited to only a few of survey days it is highly likely that on further investigations a number of additional species may be added, including rare or threatened taxa,.

Despite the low number of listed threatened species, the reserves are highly significant as isolated remnants that contain significant vegetation types. In particular Communities 5 and 6 are considered endangered within the district (Benson & Ashby 2000) and are listed on the NSW *Threatened Species Conservation Act 1995* and the Federal *Environmental Protection and Biodiversity Act 1999*. Yina Nature Reserve for example, is almost entirely landlocked by heavily cleared private lands and what remnant vegetation remains in the local vicinity is almost entirely contained within the reserve. The very small size and remnant nature of these two reserves makes them vulnerable to further degeneration unless connectedness to other remnants is assured.

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Appendix 1: Flora of Imbota and Yina Nature Reserves, Armidale NSW

Taxa found within the survey sites are scored according to their occurrence in each of the communities defined. Some taxa were found in previous surveys or opportunistically and therefore are not assigned to a specific community.

Vegetation communities

1 = *Eucalyptus caliginosa* Grassy Forest and Woodland on deep soils at Imbota

2 = *Eucalyptus viminalis* Grassy Forest and Woodland

3 = *Eucalyptus caliginosa* Grassy Forest and Woodland on shallow soils at Imbota

4 = *Eucalyptus caliginosa* Grassy Forest and Woodland at Yina

5 = *Eucalyptus blakelyi*– *Eucalyptus melliodora* Woodland

6 = *Eucalyptus viminalis*– *Eucalyptus nova-anglica* Grassy Forest and Woodland

7 = Riparian Herbfields

Nomenclature follows that of Harden (1990–1993) except where recent changes have occurred. Introduced taxa are indicated by *.

FERNS AND ALLIES							
Adiantaceae							
Adiantum aethiopicum					5		
Cheilanthes sieberi subsp. *sieberi*	1	2	3	4	5		7
Pellaea falcata					5		
Pellaea nana					5		
Pteridium esculentum							
Aspleniaceae							
Asplenium flabellifolium					5		
MONOCOTYLEDONS							
Anthericaceae							
Arthropodium milleflorum				4	5		
Tricoryne elatior		2		4	5	6	
Asphodelaceae		2		2	2	6	
Bulbine bulbosa	1						

Cyperaceae							
Carex inversa	1	2	3	4	5		
Cyperus eragrostis					5		7
Cyperus gracilis	1		3		5		
Cyperus sanguinolentus							
Cyperus sphaeroideus						6	
Eleocharis pallens							7
Eleocharis sphacelata							
Fimbristylis dichotoma	1	2		4	5	6	
Isolepis gaudichaudiana						6	
Lepidosperma laterale			3				
Schoenus ericetorum							
Scirpus polystachyus							7
Hypoxidaceae							
Hypoxis hygrometrica		2		4	5	6	
Juncaceae							
**Juncus bufonius*						6	
Juncus filicaulis	1	2					
Juncus homalocaulis					5		
Juncus remotiflorus					5		
Juncus subglaucus					5		7
Juncus subsecundus					5		7
Luzula flaccida					5		
Lomandraceae							
Lomandra filiformis	1			4			
Lomandra filiformis subsp. *coriacea*				4	5		
Lomandra longifolia	1			4			7
Lomandra multiflora subsp. *multiflora*	1	2	3	4	5		
Orchidaceae							
Pterostylis decurva							7
Pterostylis parviflora					5		
Phormiaceae							
Dianella caerulea		2	3	4	5		
Dianella revoluta					5		
Dianella revoluta var. *revoluta*	1						
Stypandra glauca							
Poaceae							
Aira cupaniana					5	6	7
Aristida jerichoensis subsp. *subspinulifera*	1						
Aristida jerichoensis var. *jerichoensis*			3				
Aristida ramosa var. *speciosa*	1	2	3	4	5	6	7
Aristida vagans	1		3			6	
Austrodanthonia induta	1						
Austrodanthonia laevis	1	2	3	4	5		
Austrodanthonia penicillata						6	
Austrodanthonia pilosa var. *pilosa*	1	2			5		
Austrodanthonia racemosa var. *obtusata*	1						
Austrodanthonia racemosa var. *racemosa*			3		5		
Austrostipa scabra subsp. *falcata*	1	2			5		
Bothriochloa bladhii subsp. *bladhii*					5	6	7
Bothriochloa decipiens					5	6	7
Chloris truncata	1				5		
Cymbopogon refractus	1	2		4	5		7
Cynodon dactylon							
Dactylis glomerata							7
Dichanthium sericeum subsp. *sericeum*	1	2			5		7
Dichelachne micrantha	1	2	3	4	5		
Echinopogon caespitosus var. *caespitosus*	1	2	3	4	5		
Echinopogon mckiei	1						
Echinopogon nutans var. *nutans*		2			5		
Entolasia stricta							
**Eragrostis curvula*							7
Eragrostis molybdea	1	2	3		5	6	
**Festuca rubra* subsp. *rubra*							7
Joycea pallida	1		3	4			
Microlaena stipoides var. *stipoides*	1	2	3	4	5	6	7
**Nasella trichotoma*							
Panicum effusum					5		
Panicum miliaceum		2			5		
Panicum simile					5		
**Paspalum dilatatum*	1	2		4	5	6	7
Paspalum distichum							7
Pennisetum alopecuroides						6	7
**Phalaris aquatica*							7
Setaria gracilis							7
**Setaria pumila*					5		
Sorghum leiocladum	1	2	3		5	6	
Sporobolus creber					5	6	
Sporobolus elongatus	1	2			5		7
Themeda australis	1	2	3	4	5		
**Vulpia bromoides*						6	
Restionaceae							
Leptocarpus tenax							7
Typhaceae							7
Typha orientalis							7
							7
DICOTYLEDONS							
Apiaceae							
Hydrocotyle laxiflora	1	2	3	4	5	6	
Hydrocotyle tripartita							
Oreomyrrhis eriopoda					5		
Asteraceae							
Ammobium alatum							7
Brachyscome heterodonta var. A				4			
Brachyscome heterodonta var. *heterodonta*		2			5		

Brachyscome melanocarpa		2					
Brachyscome radicans					5		
Brachyscome tenuiscapa var. *pubescens*					5		
Calotis cuneifolia	1	2	3	4	5		
Cassinia quinquefaria	1	2	3	4	5		
Cassinia sp. B			3				
Centipeda minima var. *minima*							
**Chondrilla juncea*							7
Chrysocephalum apiculatum		2	3	4	5	6	
Chrysocephalum semipapposum	1	2	3		5		
**Cirsium vulgare*	1				5	6	7
**Conyza albida*					5	6	7
**Conyza bonariensis*					5		
Crepis capillaris					5		
Cymbonotus lawsonianus	1	2		4	5		
Euchiton gymnocephalus	1			4	5		
Euchiton sphaericus				4			
Helichrysum scorpioides							
**Hypochaeris glabra*					5		
**Hypochaeris radicata*	1	2	3	4	5	6	7
Lagenifera stipitata	1	2	3	4	5	6	
Olearia elliptica	1	2	3				
Olearia viscidula	1	2	3	4			
Ozothamnus diosmifolius					5		
Podolepis jaccoides				4			
**Schkuhria pinnata* var. *abrotanoides*							7
Senecio bipinnatisectus							7
Senecio diaschides	1	2	3	4	5		
**Senecio madagascariensis*							7
Senecio prenanthoides		2	3				
Sigesbeckia orientalis subsp. *orientalis*				4			
Solenogyne bellioides		2					
**Sonchus oleraceus*		2					7
**Tagetes minuta*	1						
Taraxacum officinale		2	3	4	5	6	
Vernonia cinerea	1	2		4	5		
Vittadinia cuneata	1	2	3		5		
Vittadinia muelleri	1			4	5		
Vittadinia sulcata					5		
Xerochrysum bracteatum					5	6	
Boraginaceae							
Cynoglossum australe				4	5		7
Brassicaceae				4	5		7
Rorippa laciniata							7
Campanulaceae							7
Wahlenbergia communis				4	5	6	7
Wahlenbergia luteola	1	2	3		5		
Wahlenbergia planiflora subsp. *longipila*	1	2	3	4	5		
Caryophyllaceae							
**Petrorhagia nanteuilii*							7
Scleranthus biflorus	1	2	3	4	5		
**Stellaria flaccida*					5		
Casuarinaceae	1	2	3	4	2		7
Allocasuarina littoralis	1						
Chenopodiaceae							
Chenopodium pumilio	1				5		
Einadia hastata	1		3	4	5		
Einadia trigonos subsp. *leiocarpa*				4			
Clusiaceae							
Hypericum gramineum		2		4	5	6	
Hypericum japonicum		2					
Convolvulaceae							
Convolvulus erubescens						6	
Dichondra repens	1	2	3	4	5		7
Crassulaceae							
Crassula helmsii							
Crassula sieberiana					5		
Dilleniaceae							
Hibbertia obtusifolia	1	2	3	4	5		
Epacridaceae							
Brachyloma daphnoides subsp. *glabrum*	1	2		4	5		
Lissanthe strigosa	1	2	3	4	5	6	
Melichrus urceolatus	1	2	3	4	5		
Monotoca scoparia				4			
Euphorbiaceae							
Chamaesyce drummondii					5		7
Phyllanthus virgatus	1	2		4	5	6	
Poranthera microphylla							
Fabaceae							
Acacia filicifolia	1	2	3	4	5		
Acacia gunnii				4			
Acacia implexa		2	3		5		
Acacia ulicifolia		2	3	4			
Acacia viscidula				4			
Bossiaea buxifolia	1	2					
Daviesia genistifolia					5		
Daviesia latifolia				4			
Desmodium brachypodum	1	2	3	4	5		
Desmodium gunnii			3				
Desmodium varians	1	2	3	4	5	6	7
Glycine clandestina	1	2	3	4	5		
Glycine tabacina		2		4	5	6	7
Hardenbergia violacea				4	5		
Indigofera australis	1		3	4			
Jacksonia scoparia	1	2		4			
Lespedeza juncea subsp. *sericea*					5	6	7
Lotus cruentus		2	3		5		
Pultenaea microphylla	1	2	3	4	5		
**Trifolium arvense*							7
**Trifolium campestre*							7
**Trifolium repens*						6	7

Zornia dyctiocarpa subsp. *dyctiocarpa*		2					
Gentianaceae							
Centaurium erythraea	1	2			5		
Geraniaceae							
**Geranium molle* subsp. *molle*							7
Geranium solanderi var. *solanderi*	1	2	3	4	5	6	7
Goodeniaceae							
Goodenia bellidifolia subsp. *bellidifolia*				4			
Goodenia hederacea subsp. *hederacea*	1	2	3	4	5		
Haloragaceae							
Gonocarpus tetragynus		2					
Gonocarpus teucrioides			3	4	5		
Haloragis heterophylla		2		4	5	6	
**Myriophyllum aquaticum*							7
Lamiaceae							
Ajuga australis	1	2	3	4	5		
**Marrubium vulgare*	1						
Mentha diemenica	1	2	3		5	6	
Mentha satureioides			3				
Plectranthus graveolens							7
**Prunella vulgaris*							
Lobeliaceae							
Pratia pedunculata							7
Loranthaceae							
Amyema miquelii				4	5		
Amyema pendulum subsp. *pendulum*		2	3		5		
Malaceae							
**Pyracantha angustifolia*						6	
Malvaceae							
**Modiola caroliniana*						6	7
**Pavonia hastata*							7
Myrtaceae							
Angophora floribunda		2			5		
Callistemon sieberi							7
Eucalyptus blakelyi	1	2	3	4	5	6	7
Eucalyptus bridgesiana	1	2	3	4	5		
Eucalyptus caliginosa	1	2	3	4	5		7
Eucalyptus melliodora	1	2	3	4	5		
Eucalyptus nova-anglica						6	7
Eucalyptus viminalis	1	2	3		5	6	7
Oleaceae							
**Ligustrum* sp.							
Notelaea microcarpa var. *microcarpa*							
Onagraceae							
Epilobium billardierianum subsp. *hydrophilum*					5	6	7
Oxalidaceae							
Oxalis chnoodes	1	2	3	4	5	6	
**Oxalis corniculata*				4		6	7
Oxalis perennans					5		
Pittosporaceae							
Bursaria spinosa				4	5	6	
Plantaginaceae							
Plantago debilis	1	2			5		
**Plantago lanceolata*		2	3		5	6	7
Plantago varia	1	2	3		5		
Polygalaceae							
Polygala japonica				4			
Polygonaceae				4			
Persicaria hydropiper						6	7
Rumex brownii	1		3	4	5	6	7
**Rumex crispus*							7
Portulacaceae							
Portulaca oleracea							
Primulaceae							
**Anagallis arvensis*	1						7
Rhamnaceae							
Cryptandra amara var. *amara*	1						
Rosaceae							
Acaena novae-zelandiae	1	2	3	4	5	6	7
Acaena ovina					5	6	
**Rosa rubiginosa*		2			5	6	
**Rubus chloocladus*					5	6	7
Rubus parvifolius	1	2			5		
Rubiaceae							
Asperula conferta	1	2			5	6	7
Galium binifolium							
Galium gaudichaudii		2	3		5		
Nertera granadensis	1						
Opercularia diphylla	1	2	3	4	5		
Pomax umbellata		2			5		
Salicaceae							
**Salix babylonica*							7
Santalaceae							
Exocarpos cupressiformis	1				5		
Scrophulariaceae							
Gratiola pedunculata							
Veronica calycina		2	3		5		
Solanaceae							
**Solanum nigrum*	1	2	3			6	
Stackhousiaceae							
Stackhousia monogyna					5		7
Stackhousia viminea	1	2	3				
Urticaceae							
Urtica incisa	1						
Verbenaceae							
**Verbena bonariense*							7
**Verbena rigida*					5	6	7
Violaceae							
Hybanthus monopetalus		2		4			
Viola betonicifolia	1	2	3	4	5		
Viola hederacea					5	6	

Bryophytes and their distribution in the Blue Mountains region of New South Wales

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***Abstract*:** The bryophytes (mosses, liverworts and hornworts) that occur in the Blue Mountains region of New South Wales (latitude 33°–34° S, longitude 151°–151°40' E) are listed and information is provided on their distribution in the region. Species lists are based on herbarium specimens and field collections.

348 bryophyte taxa have been recorded from 70 families, including 225 moss taxa (in 108 genera from 45 families), 120 liverwort taxa (in 51 genera from 24 families) and 3 hornwort taxa (in 3 genera from one family). The moss families with most taxa are the Pottiaceae (with 23 taxa in 13 genera), Bryaceae (with 15 taxa in 3 genera) and Fissidentaceae (with 13 taxa). The largest genera are *Fissidens* (13 taxa), *Campylopus* (9) and *Macromitrium* (8). The liverwort family with the most taxa is Lepidoziaceae, with 29 taxa in 10 genera. The largest liverwort genera are *Frullania* (11 taxa) and *Riccardia* (8).

The species lists include collections from both bushland and urban areas. Natural features of the Blue Mountains, including topography, altitude, climate and vegetation appear to be important factors influencing the number of bryophyte species recorded from each location. The number of collections from particular locations has been considerably influenced by ease of access, particularly proximity to roads, public transport and railway stations. The species lists include many records from areas that were not accessible to the early collectors of the late 19th and early 20th centuries such as Wollemi National Park, Gardens of Stone National Park, Newnes Plateau and Kanangra-Boyd National Park.

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Introduction

The Blue Mountains region, 60 km west of Sydney, is an area of rugged beauty with considerable variety in landscape and vegetation. Perhaps it should more realistically be referred to as the 'Blue Mountains Plateau', a title that reflects more accurately the deeply dissected sandstone plateau, with its sheer sandstone cliffs and deep gorges. The Greater Blue Mountains World Heritage Area was inscribed on the World Heritage List in 2000, principally for the great diversity of *Eucalyptus* species that occur within the area (Department of Environment & Heritage 2003). Bryophytes include mosses, liverworts and hornworts, and are a fascinating group of non-vascular plants that have been overlooked in most botanical and ecological studies. We list some 350 bryophyte taxa (mosses, liverworts and hornworts) that occur in the Blue Mountains and provide information on bryophyte distribution in the region.

Location

Our study area includes the Blue Mountains region from the Nepean River in the east, to the sheer cliffs of Lithgow, Hartley and Portland in the west, as well as parts of the Great Dividing Range, from Mount Colong and Colong Caves in the south, to the Capertee River in the north (Figure 1). The area (latitude 33°–34° S, longitude 151°–151°40' E), approximately 40 km east to west and 120 km north to south, takes in part of the Central Coast and the Central Tablelands Botanical Divisions of New South Wales. The area includes Blue Mountains National Park, Kanangra Boyd National Park, Wollemi National Park, Gardens of Stone National Park, council reserves, state forests, crown lands, urban parks and private gardens.

Topography/geology

The Blue Mountains plateau rises rapidly immediately west of the Nepean River and then slopes gradually westwards to its highest elevations just over 1000 m a.s.l. near Blackheath, Mount Victoria and the Newnes Plateau (Figures 1 & 2). The uppermost section of the plateau is sandstone, deposited in massive river deltas during the Triassic Period, 180 million years ago. At the edges of the sandstone massive cliffs form, as the gradual slopes formed by the underlying Permian coal-bearing shales erode more rapidly than sandstone above, undercutting the sandstone and leading to massive cliff wall collapses (Figure 2). In the most spectacular gorges of the upper Blue Mountains, the sandstone has been deeply dissected by streams and rivers, and many valleys are lined with sheer sandstone cliffs. Visible in various locations are shale bands sandwiched between sandstone layers. Vertical-walled slot canyons occur at many places, the deepest occurring near Mt Banks and Mt Wilson, and along the western and northern edges of the Newnes Plateau.

In lower areas of the Blue Mountains, such as the Blue Labyrinth, south and east of Springwood, the plateau has been dissected to form an extensive network of steep, sandstone ridges with small cliffs and sandstone outcrops (Prosser 1994).

Triassic shales cap sandstone between Kurrajong and Mount Tomah on Bells Line of Road and near Springwood on the Great Western Highway.

Tertiary basalt caps (1000 m a.s.l.) occur at Mount Wilson, Mount Irvine (7 km north east of Mount Wilson), Mount Tomah, Mount Banks and Mount Hay (14 km north east of Katoomba). These were originally lava flows along valleys, but following erosion of the softer sandstone of the surrounding landforms, they now form some of the few distinctive peaks of the Blue Mountains plateau (Branagan & Packham 2000).

The oldest geological formations are those of Early Permian and Mid Permian of Kanangra-Boyd National Park. The sheer sandstone cliffs at Kanangra Walls are very similar in appearance to the Triassic sandstones of the upper Blue Mountains. There are outcrops of Carboniferous granodiorite at Boyd River Crossing on the Jenolan Caves to Kanangra Road and limestone at Colong (Prosser 1994).

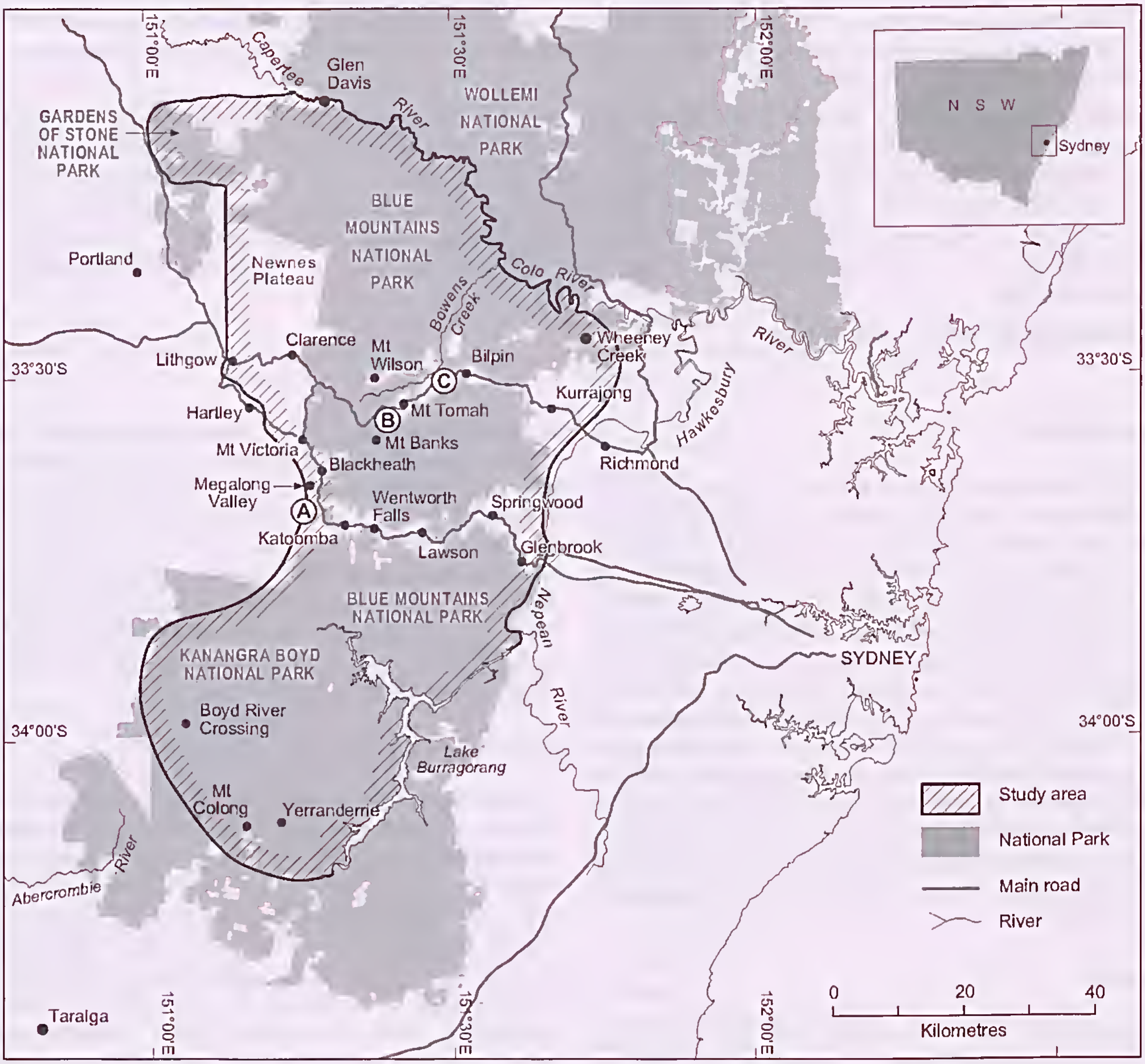

Fig. 1. Blue Mountains region and study area. (A) (B) (C) relate to geological section in Figure 2.

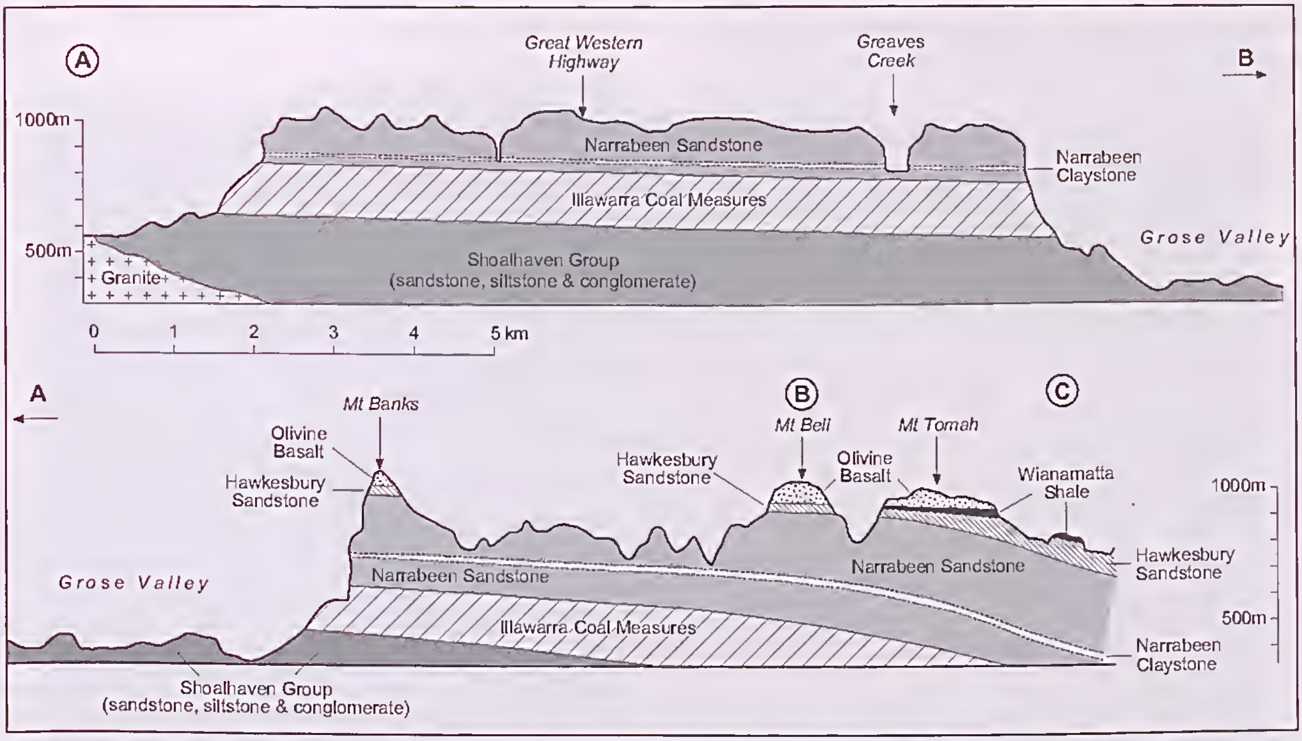

Fig. 2. Section showing geological strata and landforms along (A) (B) (C) in Figure 1. (Modified from Geological Survey of New South Wales 1997)

Climate

Rainfall is significantly higher in the upper mountains (1200–1400 mm p.a.) than in lower areas to the east and west (about 700–800 mm) (Table 1). The basalt peaks are high points (above 1000 m a.s.l.) on the Blue Mountains plateau, and correspondingly their rainfall is higher than surrounding areas. Mount Tomah has an annual average rainfall of 1541 mm and probably similar rainfall is experienced at the other high peaks (Rodd 1987). Rainfall is relatively evenly distributed throughout the year, but slightly lower in winter. Cloud, mist and fog are not uncommon and snow falls occasionally in winter on the higher parts above 1000 m.

Temperatures in the Blue Mountains are cooler both in summer and in winter than those in Sydney (Table 1). In general, temperatures are higher in areas to the north-west of the area (eg Glen Davis) but rainfall is much lower, about 650 mm per annum. To the south, (Taralga) temperatures are close to those of the higher Blue Mountains, but rainfall is lower, about 800–900 mm p.a. (Commonwealth Bureau of Meteorology 2006).

Table 1. Climatic Records for sites in and near the Blue Mountains study area (Mount Tomah data from Rodd (1987), other sites from Commonwealth Bureau of Meteorology (2006)).

Measurement	Sydney	Richmond	Mt Tomah	Katoomba	Mt Victoria	Lithgow	Glen Davis	Taralga
Metres above sea level	39	19	1016	1030	1064	950	282	845
Mean daily maximum temperature for January °C	25.8	29.6	26.5	23.1	23.0	25.5	30.3	25.7
Highest maximum temperature for January °C	45.3	47.8	N/A	36.1	35.5	37.7	N/A	38.8
Mean daily minimum temperature for July °C	8.0	3.6	3.6	2.5	1.7	0.7	2.0	0.6
Lowest minimum temperature for July °C	2.2	-8.3	-5.0	-8.2	-6.3	-8.0	N/A	-9.6
Rainfall mm per annum	1217	810	1541	1402	1061	863	634	804
Cloudy days per annum	134	123	N/A	148	126	142	N/A	124

Table 2. Distribution of Bryophytes in relation to topography and vegetation in Greaves Creek Valley, Blackheath NSW
Open forest dominated by *Eucalyptus piperita* and *Eucalyptus sieberi*, Forest dominated by *Eucalyptus oreades* and *Callicoma serratifolia*, Closed forest dominated by *Ceratopetalum apetalum* and *Doryphora sassafras*.
Table modified from Selkirk, Adamson & Downing (2001).

Taxa	Open Forest Plateau	Forest Valley Side	Closed Forest Deep Gully
Breutelia pendula	1		
Campylopus clavatus	1		1
Cephaloziella exiliflora	1		
Ditrichum difficile	1		1
Ditrichum punctulatum	1		
Eucamptodon muelleri	1		1
Frullania rostrata	1		1
Frullania squarrosula	1		
Goebelobryum unguiculatum	1		
Kurzia compacta	1		
Lepidozia ulothrix	1		1
Lethocolea pansa	1		1
Pogonatum subulatum	1		1
Rhacocarpus purpurascens	1	1	
Sclerodontium pallidum	1		
Sematophyllum contiguum	1		
Telaranea elegans	1		1
Tortula muralis	1		
Andreaea nutabilis		1	1
Balantiopsis diplophylla		1	1
Bartramia hampeana		1	
Bazzania involuta		1	1
Campylopus introflexus		1	
Chiloscyphus coalitus			1
Chiloscyphus limosus		1	
Dicranoloma billardieri		1	1
Leucobryum candidum		1	1
Rhapidorrhynchium amoenum		1	1
Rhizogonium novaehollandiae		1	
Symphyogyna podophylla		1	1
Achrophyllum dentatum			1
Acromastigum colensoanum			1
Andreaea subulata			1
Breutelia affinis			1
Rosulabryum billarderi			1
Heteroscyphus fissistipus			1
Ctenidium pubescens			1
Dawsonia superba			1
Dicranoloma dicarpum			1
Dicranoloma menziesii			1
Distichophyllum crispulum			1
Distichophyllum pulchellum			1
Fissidens humilis			1
Fissidens pallidus			1
Frullania falciloba			1
Frullania monocera			1
Hampeella pallens			1
Paracromastigum longiscyphum			1
Hymenophyton flabellatum			1
Hypnodendron vitiense			1
Hypnum cupressiforme			1
Isopterygium limatum			1
Kurzia hippuroides			1
Chiloscyphus semiteres			1
Solenostoma inundatum			1
Macromitrium archeri			1
Macromitrium ligulaefolium			1
Marsupidium surculosum			1
Megaceros gracilis			1
Mittenia plumula			1
Papillaria crocea			1
Papillaria flavolimbata			1
Plagiochila fasciculata			1
Podomitrium phyllanthus			1
Porella crawfordii			1
Ptychomnium aciculare			1
Pyrrhobryum mnioides			1
Pyrrhobryum paramattense			1
Radula buccinifera			1
Riccardia aequicellularis			1
Riccardia bipinnatifida			1
Riccardia colensoi			1
Riccardia crassa			1
Sphagnum cristatum			1
Thuidiopsis sparsa			1
Wijkia extenuata			1
Zoopsis leitgebiana			1
Zoopsis setulosa			1

Vegetation

The vegetation of the Blue Mountains area has been documented by Keith & Benson (1988), James & Kodela (1994), and Harden (1994). *Eucalyptus* woodland dominates the vegetation of the plateaus and ridges, with mallee eucalypts often growing in shallow soils over sandstone rock. Hanging swamps occur in many parts of the Blue Mountains where shallow soils of clay and peat accumulate over impervious rock. Dry heaths may be found on the tops of sandstone cliffs, particularly where exposed to southerly and southwesterly winds. Granite heath is restricted to granite outcrops above 1100 m in Kanangra-Boyd National Park.

The soils of the gentle slopes that lie below the sheer sandstone cliffs are richer in nutrients and have a better capacity to retain water than the plateau sandstone soils. Aspect plays an important part in the development of the vegetation in these lower valleys. North facing slopes such as in the Grose Valley below Blackheath tend to be dominated by *Eucalyptus* woodland or forest. (Figure 3) Southern slopes, such as Megalong Valley to the south of Blackheath, and below the scenic railway at Katoomba, support closed forest, or tall, open or closed *Eucalyptus* forest.

Soils derived from shales have better moisture retention than those derived from sandstone, thus *Eucalyptus* forest occurs in shale gullies and on clay based soils that cap sandstones, for example at Springwood and Bilpin. Many of these areas have been cleared for orchards (along Bells Line of Road) or for urban development along the railway towns of the lower Blue Mountains.

High light, high temperatures, desiccating winds and frequent fire have limited rainforest to south and east facing slopes, bottoms of moist, sheltered gorges with alluvial soils, and shales and Coal Measures on sheltered sites below cliffs. Closed forest species include *Doryphora sassafras, Ceratopetalum apetalum, Callicoma serratifolia* and the tree ferns, *Cyathea* spp. and *Dicksonia antarctica* (vascular plant names follow those currently recognised at the National Herbarium of New South Wales). Similar vegetation is found on the nutrient-rich, moisture retentive soils of the basalt caps (Harden 1994). In the slot canyons, formed by the rapid erosion of vertical fault lines in sandstone, light levels are so low that only ferns and bryophytes survive.

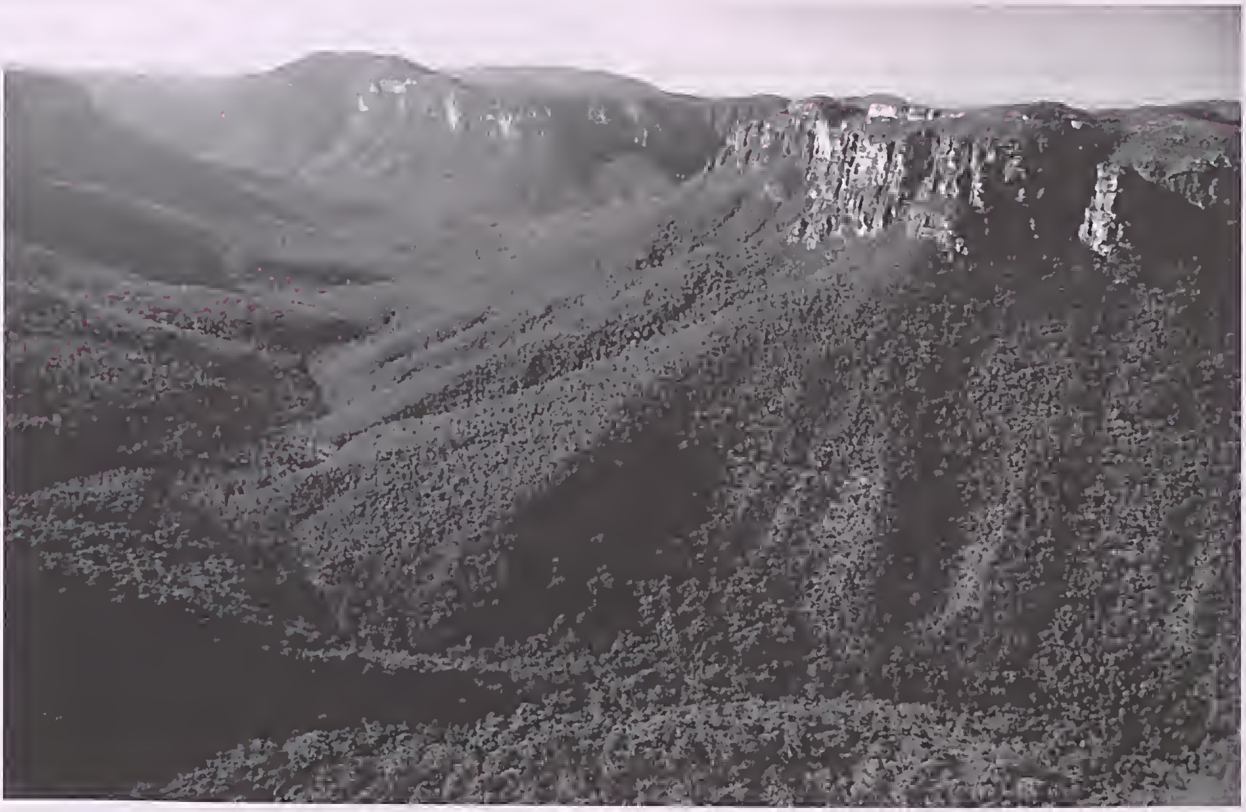

Fig. 3. View northwards from Blackheath across the Grose Valley to Mount Banks. *Eucalyptus* woodland dominates vegetation on the plateau while *Eucalyptus* forest grows on the slopes below the sandstone cliffs. Mixed *Eucalyptus* and closed forest clothe the basalt cap of Mount Banks.

Bryophyte studies

The earliest published bryophyte records for the Blue Mountains are in Forsyth's (1899) list of 61 moss species for New South Wales, which included seven species collected in the Blue Mountains. Watts & Whitelegge's (1902, 1905) two lists of Australian mosses included species from the Blue Mountains. Burges (1932, 1935) updated this list, including 17 records from the Blue Mountains. Stephani & Watts (1914) described at least 25 species of liverworts based on specimens from the Blue Mountains. Ramsay's (1984) *Census of New South Wales Mosses* listed 204 moss taxa for the New South Wales Central Tablelands Botanical Subdivision which includes part of the Blue Mountains.

A list of bryophytes occurring in the Blue Mountains region was prepared by H. Ramsay and P. Selkirk for inclusion in the documentation for World Heritage Listing of the Blue Mountains (ed. T. James 1994). This species list included 247 moss taxa, 122 liverwort taxa and one hornwort, but covered a significantly greater area including Nattai, Goulburn River and Dharug National Parks, than the current study.

Recent studies of particular sites include Mount Tomah Botanic Gardens where Ramsay, Downing & Schofield (1990) listed 85 bryophyte taxa (63 mosses, 21 liverworts and one hornwort). The list includes taxa from both the gardens and forest on the basalt cap and from areas of natural woodlands and forest growing on shales and sandstones of adjoining areas. A study of landform and vegetation of the Greaves Creek Basin, near Blackheath (Selkirk, Adamson & Downing 2001), includes a species list for the valley, information important in understanding bryophyte distribution in relation to the deep canyon topography of the Blue Mountains.

The bryoflora of the limestone areas of Jenolan and Wombeyan are particularly interesting but are very different from the bryophyte assemblages of the predominant sandstones, shales and basalt caps of the Blue Mountains that this paper highlights. Jenolan and Wombeyan have been excluded from this study because they lie marginally outside the study area, and because there are already a number of publications on their bryoflora (Downing 1992; Downing, Ramsay & Schofield 1991; Downing, Oldfield & Selkirk 1995). However, collections by Roger Carolin (John Ray Herbarium, SYD) from limestones near Colong Caves have been included as there are no previously published records from this area which is in Kanangra-Boyd National Park.

Methods

Records of bryophytes (mosses, liverworts and hornworts) that occur in the Blue Mountains region of New South Wales (latitude 33°–34° S, longitude 151°–151°40' E) were tabulated by geographical areas based on species lists from field collections and herbarium records.

During the last 25 years, the authors have made regular field trips to the Blue Mountains for a variety of purposes, including collecting bryophytes for taxonomic and genetic studies, and for teaching. The resulting collections, now variously housed at the National Herbarium of New South Wales (NSW), University of Sydney (SYD) and Macquarie University, have provided the base for this work. Geographically based species lists from Ramsay, Downing & Schofield (1990), and Selkirk, Adamson & Downing (2001), vouchers for which are held at Macquarie University, have been included. Lists of bryophyte species collected, at each Blue Mountains field trip location, by participants of the Australasian Bryological Workshop held in the Blue Mountains in 2001 have also been included.

Other records of bryophytes from the Blue Mountains were sought from herbaria, including the National Herbarium of New South Wales (NSW), the Downing Herbarium at Macquarie University, the John Ray Herbarium at University of Sydney (SYD), the Australian National Herbarium (CANB) and the National Herbarium of Victoria (MEL). Previously unpublished specimen-based records include approximately 2000 mosses and 1000 liverwort records.

Records were grouped for locations with similar geography and elevation. For example, Lapstone, Glenbrook, Blaxland and Mount Riverview have been grouped under Glenbrook; Valley Heights, Springwood and Faulconbridge have been grouped under Springwood. Locations range from low elevations at Glenbrook to high elevations at Blackheath and Newnes Plateau, and include sites on a range of geological substrates including sandstone, shale and basalt.

For the most part, collected material was returned to the laboratory, and identified using published keys, such as *Mosses of Southern Australia* (Scott & Stone 1976), *Southern Australian Liverworts* (Scott 1985), *Mosses of South Australia* (Catcheside, 1980) and *The Mosses of New Zealand* (Beever, Allison & Child 1992). More recently, the *Key to the Genera of Australian Mosses* (Buck, Vitt & Malcolm 2002) has been a valuable addition to this list. Also invaluable have been a raft of taxonomic papers published in recent years that have allowed accurate identification of particular taxa, for example: Bryaceae (Spence & Ramsay 1996, 1999), *Dicranoloma* (Klazenga 2003), Funariaceae (Fife & Seppelt 2001), *Grimmia* (Greven 2000), Hookeriaceae (Streimann 1997), *Macromitrium* (Vitt & Ramsay 1985), Sematophyllaceae (Ramsay, Schofield & Tan 2002), *Sphagnum* (Seppelt 2000), *Papillaria* (Streimann 1991) and as yet unpublished taxonomic keys prepared by S. Gilmore (Echinodiaceae and Fabroniaceae).

Taxonomy and allocation to families for moss taxa follows Streimann & Klazenga (2002) with the exception of some Bryaceae taxa, for which we have referred to Spence & Ramsay (2006). Taxonomy and allocation to families for liverwort and hornwort taxa follows McCarthy (2003). New state records for mosses, liverworts and hornworts were determined from the respective *Catalogues*. Records of moss taxa new for the Central Tablelands Botanical Division have been determined from Ramsay's (1984) *Census of New South Wales Mosses*. Authorities for taxa that occur in the Blue Mountains are included in Tables 3 & 4.

The following notation has been used where relevant in the text and in the appendices.

* Indicates an introduced species.
ᶜ Indicates a cosmopolitan species.
† Indicates an Australian endemic species.
# Indicates a new record for New South Wales.

Results

We have tabulated records of 348 bryophyte taxa for the Blue Mountains region. The moss taxa comprise 225 moss species in 108 genera and 45 families (Table 3), and include 23 Australian endemics and eight new species records for New South Wales. The moss families with most taxa were the Pottiaceae with 23 species in 13 genera, Bryaceae with 15 species in 3 genera and Fissidentaceae with 13 species of *Fissidens*. *Calomnion complanatum*, previously known in New South Wales only from Cambewarra Mountain on the south coast, is reported from Mount Wilson and Rocky Creek on the Newnes Plateau.

Liverwort taxa include 120 taxa in 51 genera in 24 families (Table 4), including eight species that are new records for New South Wales. There were many more species of Lepidoziaceae (29 species in 10 genera) than there were of any other liverwort family. The rare liverwort *Haplomitrium intermedium* is recorded from Bowens Creek and Lawson. Elsewhere in New South Wales it is only known from Kuring-gai Chase National Park. *Enigmella thallina* was observed (but not collected) by K. Beckman at Pierces Pass near Mount Banks (K. Beckman pers. comm.). It has not been previously recorded from the Blue Mountains.

Hornwort taxa included three species from three genera in one family (Table 4), adding two species and two genera to Ramsay & Selkirk's 1994 listing.

Table 3: Mosses of the Blue Mountains Region

G = Glenbrook + Lapstone + Blaxland, S = Springwood + Valley Heights + Faulconbridge, La = Lawson + Woodford + Hazelbrook, WF = Wentworth Falls, Ka = Katoomba, KB = Kanangra-Boyd, C = Colong + Yerranderie, Bl = Blackheath, Mg = Megalong Valley, MV = Mount Victoria, Li = Lithgow + Clarence, N = Newnes Plateau, MB = Mt Banks + Pierces Pass, MW = Mount Wilson + Mount Irvine, T = Mount Tomah, WC = Wheeney Creek + Mountain Lagoon, BC = Bowens Creek, Bi = Bilpin, Ku = Kurrajong, BM = Blue Mountains (locality unknown).

† indicates that the species is an Australian endemic (Streimann & Klazenga 2002)

New records for NSW (Streimann & Klazenga 2002)

* Introduced species

ᶜ Cosmopolitan species

Family/Taxon	G	S	La	WF	Ka	KB	C	Bl	Mg	MV	Li	N	MB	MW	T	WC	BC	Bi	Ku	BM
Andreaeaceae																				
† # *Andreaea amblyophylla* Müll. Hal. ex Broth.								Bl												
Andreaea mutabilis Hook.f. & Wilson				WF	Ka			Bl												
Andreaea subulata Harv. ex Hook.				WF	Ka			Bl												
Bartramiaceae																				
†*Bartramia hampeana* Müll. Hal. subsp. *hampei* (Mitt.) Fansén						KB		Bl												
Bartramia ithyphylla Brid.						KB		Bl	Mg					MW						
Breutelia affinis (Hook.) Mitt.			La	WF				Bl	Mg					MW			BC	Bi		
Breutelia pendula (Sm.) Mitt.			La	WF	Ka	KB		Bl			Li	N	MB	MW	T					
†*Breutelia pseudophilonotis* (Müll.Hal.) Watts & Whitelegge			La					Bl			Li	N		MW				Bi		
Conostomum pusillum Hook.f. & Wilson var. *pusillum*				WF	Ka	KB		Bl												
Philonotis scabrifolia (Hook.f. & Wilson) Braithwaite			La	WF					Mg					MW						
Philonotis tenuis (Taylor) Reichardt			La				C	Bl							T	WC				
†*Philonotis tortifolia* (Müll.Hal.) Watts & Whitelegge				WF										MW						
Brachytheciaceae																				
**Brachythecium albicans* (Hedw.) Schimp.								Bl		MV										
ᶜ*Brachythecium rutabulum* (Hedw.) Schimp.			La																	
**Pseudoscleropodium purum* (Hedw.) M.Fleisch. ex Broth.								Bl	Mg											
Rhynchostegium laxatum (Mitt.) Paris								Bl						MW						
Rhynchostegium muriculatum (Hook.f. & Wilson) Reichardt														MW						
Rhynchostegium tenuifolium (Hedw.) Reichardt var. *tenuifolium*				WF	Ka			Bl	Mg					MW	T		BC			
Bruchiaceae																				
Trematodon longescens Müll.Hal.								Bl											Ku	
Bryaceae																				
ᶜ*Bryum argenteum* Hedw.			La		Ka			Bl		MV	Li		MB	MW	T	WC				
Bryum lanatum P. Beauv.								Bl			Li	N				WC	BC			

Family/Taxon	**G**	**S**	**La**	**WF**	**Ka**	**KB**	**C**	**Bl**	**Mg**	**MV**	**Li**	**N**	**MB**	**MW**	**T**	**WC**	**BC**	**Bi**	**Ku**	**BM**
Gemmabryum apiculatum (Schwägr.) J.R.Spence & H.P.Ramsay															T					
Gemmabryum chrysoneuron (Müll.Hal.) J.R.Spence & H.P.Ramsay								Bl												
Gemmabryum coronatum (Schwägr.) J.R.Spence & H.P.Ramsay				WF				Bl												
Gemmabryum dichotomum (Hedw.) J.R.Spence & H.P.Ramsay	G			WF				Bl			Li		MB	MW	T		BC			
†*Gemmabryum eremaeum* (Catches.) J.R.Spence & H.P.Ramsay																				BM
Gemmabryum pachythecum (Müll.Hal.) J.R.Spence & H.P.Ramsa var. *pachythecum*	G																			
Gemmabryum sauteri (Bruch & Schimp.) J.R.Spence & H.P.Ramsay															T					
Rosulabryum albolimbatum (Hampe) J.R.Spence			La																	
Rosulabryum billarderi (Schwägr.) J.R.Spence		S	La	WF	Ka			Bl	Mg					MW	T		BC	Bi		BM
Rosulabryum capillare (Hedw.) J.R.Spence			La					Bl							T					
Rosulabryum subfasciculatum (Hampe) J.R.Spence		S	La	WF												WC			Ku	
Rosulabryum subtomentosum (Hampe) J.R.Spence				WF																
Rosulabryum torquescens (Hampe) J.R.Spence			La	WF	Ka		C	Bl	Mg											
Callicostaceae																				
Sauloma tenella (Hook.f. & Wilson) Mitt.														MW						
Calomniaceae																				
Calomnion complanatum (Hook.f. & Wilson) Lindb.												N		MW						
Cryphaeaceae																				
Cryphaea tenella (Schwägr) Hornsch. ex Müll.Hal.													MB	MW	T					
†*Cyptodon muelleri* (Hampe) M.Fleisch.														MW						
Dicranaceae																				
Dicranella dietrichiae (Müll.Hal.) A. Jaeger		S		WF				Bl	Mg	MV				MW	T		BC		Ku	
Dicranoloma billarderi (Brid. ex Anon.) Paris			La	WF				Bl	Mg	MV	Li		MB	MW					Ku	
Dicranoloma dicarpum (Nees) Paris			La					Bl	Mg			N		MW			BC			
†*Dicranoloma leichhardtii* (Hampe) Watts & Whitelegge		S	La	WF				Bl	Mg				MB	MW	T		BC	Bi		
Dicranoloma menziesii (Taylor) Reynauld			La	WF				Bl	Mg	MV			MB	MW				Bi		
Encamptodon muelleri Hampe & Müll.Hal. var. *muelleri*			La	WF	Ka	KB		Bl		MV	Li	N	MB	MW			BC			
Holomitrium perichaetiale (Hook.) Brid. var. *perichaetiale*			La	WF	Ka			Bl						MW						
Sclerodontium pallidum (Hook.) Schwägr. subsp. *pallidum*	G	S	La	WF	Ka	KB	C	Bl	Mg	MV	Li	N	MB	MW	T	WC	BC	Bi	Ku	
Ditrichaceae																				
[c]*Ceratodon purpureus* (Hedw.) Brid. subsp. *convolutus* (Reichardt) Burley		S	La	WF	Ka	KB	C	Bl		MV	Li	N	MB	MW	T			Bi		
Ditrichum brevirostre (R.Br.bis) Broth.			La					Bl												

Ditrichum cylindricarpum (Müll.Hal.) F.Muell.								Bl		MV			MW			BC			
Ditrichum difficile (Duby) M.Fleisch.		S	La	WF	Ka	KB		Bl	Mg	MV	Li	N	MW	T		BC			
# *Ditrichum punctulatum* Mitt.								Bl											
Eccremidium brisbanicum (Broth.) I.G.Stone & G.A.M.Scott								Bl											
Pleuridium nervosum (Hook.) Mitt.				WF					Mg	MV									
Entodontaceae																			
Entodon mackaviense Müll.Hal.							C							T					
Fabroniaceae																			
Fabronia australis Hook.			La		Ka									T					
†*Fabronia scottiae* Müll.Hal.							C								WC				
Fissidentaceae																			
# *Fissidens adianthoides* Hedw.								Bl											
^{c}*Fissidens asplenioides* Hedw.	G		La	WF					Mg			N	MW				Bi		
Fissidens curvatus Hornsch. var. *curvatus*			La	WF				Bl					MW	T					
Fissidens leptocladus Müll.Hal.							C	Bl	Mg					T					
Fissidens linearis Brid. var. *linearis*		S	La	WF				Bl	Mg					T					BM
Fissidens megalotis Schimp. ex Müll.Hal.													MW						
Fissidens oblongifolius Hook.f. & Wilson var. *oblongifolius*		S	La	WF	Ka			Bl	Mg	MV			MW		WC			Ku	
Fissidens oblongifolius Hook.f. & Wilson var. *hyophilus* (Mitt.) Beever & I.G.Stone					Ka														
Fissidens pallidus Hook.f. & Wilson var. *pallidus*	G		La	WF	Ka			Bl	Mg	MV		N	MW	T	WC	BC	Bi		
Fissidens rigidulus Hook.f. & Wilson var. *rigidulus*													MW						
Fissidens taylorii Müll.Hal var. *taylorii*							C		Mg					T					
†*Fissidens tenellus* Hook.f. & Wilson var. *australiensis* (A.Jaeger) Beever & I.G.Stone				WF															
Fissidens tenellus Hook.f. & Wilson var. *tenellus*		S	La	WF			C		Mg		Li		MW	T					
Funariaceae																			
Entosthodon apophysatus (Taylor) Mitt.										MV									
Entosthodon muehlenbergii (Turner) Fife	G		La	WF															
Entosthodon radians (Hedw.) Müll.Hal.	G			WF														Ku	
Entosthodon subnudus (Taylor) Fife var. *gracilis* (Hook.f. & Wilson) Fife																			BM
^{c}*Funaria hygrometrica* Hedw.		S	La	WF	Ka		C				Li	N	MW	T					BM
Grimmiaceae																			
Grimmia austrofunalis Müll.Hal.					Ka														
^{c}*Grimmia laevigata* (Brid.) Brid.						KB		Bl		MV			MW						
^{c}*Grimmia pulvinata* (Hedw.) Sm. var. *africana* (Hedw.) Hook.f. & Wilson				WF	Ka	KB	C	Bl		MV			MW	T			Bi		
Grimmia trichophylla Grev.					Ka	KB													
Racomitrium crispulum (Hook.f. & Wilson) Hook.f. & Wilson var. *crispulum*						KB			Mg		Li								

Racomitrium pruinosum (Wilson) Müll.Hal.						KB									T					
ᶜ*Schistidium apocarpum* (Hedw.) Bruch & Schimp.															T					
Family/Taxon	**G**	**S**	**La**	**WF**	**Ka**	**KB**	**C**	**Bl**	**Mg**	**MV**	**Li**	**N**	**MB**	**MW**	**T**	**WC**	**BC**	**Bi**	**Ku**	**BM**
Hedwigiaceae																				
ᶜ*Hedwigia ciliata* (Hedw.) P.Beauv.					Ka	KB	C						MB	MW						
ᶜ*Hedwigidium integrifolium* (P.Beauv.) Dixon					Ka	KB		Bl				N	MB	MW	T					
Hookeriaceae																				
Achrophyllum dentatum (Hook.f. & Wilson) Vitt & Crosby			La		Ka			Bl	Mg			N		MW		WC	BC	Bi		
Distichophyllum crispulum (Hook.f. & Wilson) Mitt.			La		Ka			Bl			Li	N				WC		Bi		BM
Distichophyllum microcarpum (Hedw.) Mitt.				WF										MW						BM
Distichophyllum pulchellum (Hampe) Mitt.		S	La	WF	Ka			Bl	Mg		Li	N		MW					Ku	
Distichophyllum rotundifolium (Hook.f. & Wilson) Müll.Hal. & Broth.				WF	Ka													Bi		
Hypnaceae																				
Ctenidium pubescens (Hook.f. & Wilson) Broth.			La	WF				Bl												
ᶜ*Hypnum cupressiforme* Hedw. var. *cupressiforme*			La		Ka	KB		Bl						MW						
Hypnum cupressiforme Hedw. var. *mossmanianum* (Müll.Hal.) Ando				WF	Ka			Bl				N		MW	T					
# *Isopterygium limatum* (Hook.f. & Wilson) Broth.			La	WF			C	Bl	Mg			N	MB	MW	T	WC		Bi	Ku	
Hypnodendraceae																				
Hypnodendron vitiense Mitt. subsp. *australe* Touw		S	La	WF	Ka			Bl	Mg	MV	Li	N	MB	MW	T	WC	BC	Bi	Ku	
Hypopterygiaceae																				
Cyathophorum bulbosum (Hedw.) Müll.Hal.									Mg					MW						
Hypopterygium didictyon Müll.Hal.									Mg					MW						
Hypopterygium tamarisci (Sw.) Brid. ex Müll.Hal.			La	WF	Ka			Bl	Mg				MB	MW	T	WC	BC	Bi	Ku	
Lopidium concinnum (Hook.) Wilson			La	WF	Ka			Bl	Mg		Li	N	MB	MW			BC	Bi		BM
Lembophyllaceae																				
#*Camptochaete arbuscula* (Sm.) Reichardt var. *arbuscula*									Mg					MW	T					
Camptochaete deflexa (Wilson) A.Jaeger															T					
†*Camptochaete excavata* (Taylor) A.Jaeger				WF			C	Bl	Mg					MW	T					
Fallaciella gracilis (Hook.f. & Wilson) H.A.Crum														MW	T					
Lembophyllum divulsum (Hook.f. & Wilson) Lindb. var. *divulsum*			La				C	Bl				N		MW	T	WC				
Weymouthia mollis (Hedw.) Broth.														MW						
Leptodontaceae																				
Leptodon smithii (Hedw.) F.Weber & D.Mohr				WF										MW	T	WC				
Leptostomataceae																				

†*Leptostomum erectum* R.Br.				WF				Bl	Mg					MW	T					
Leptostomum inclinans R.Br.				WF				Bl	Mg			N		MW	T					
Leskeaceae																				
Pseudoleskeopsis imbricata (Hook.f. & Wilson) Thér.					Ka		C													
Leucobryaceae																				
Campylopus acuminatus Mitt. var. *acuminatus*			La					Bl							T					
†*Campylopus australis* Catches. & J.-P.Frahm			La		Ka			Bl		MV										
Campylopus bicolor (Hornsch. ex Müll.Hal.) Wilson			La	WF	Ka	KB		Bl						MW						
Campylopus catarractilis (Müll.Hal.) Paris				WF				Bl		MV										
Campylopus clavatus (R.Br.) Wilson			La	WF		KB		Bl						MW		WC	BC	Bi		
†*Campylopus flindersii* Catches. & J.-P.Frahm				WF				Bl			Li									
Campylopus incrassatus Müll.Hal.			La	WF				Bl					MB	MW						
Campylopus introflexus (Hedw.) Brid.			La	WF	Ka	KB		Bl		MV	Li	N	MB	MW	T	WC	BC	Bi	Ku	
Campylopus pyriformis (Schultz) Brid.	G	S		WF	Ka			Bl						MW						
# *Leucobryum aduncum* Dozy & Molk. var. *aduncum*		S	La	WF	Ka			Bl				N						Bi		BM
# *Leucobryum aduncum* Dozy & Molk. var. *scalare* (Müll.Hal. ex M.Fleisch.) A. Eddy																		Bi		
Leucobryum candidum (Brid. ex P.Beauv.) Wilson		S	La	WF				Bl	Mg	MV	Li	N	MB	MW	T	WC	BC	Bi		
†*Leucobryum turgidulum* Müll.Hal.					Ka															
Meteoriaceae																				
Papillaria crocea (Hampe) A.Jaeger				WF	Ka			Bl			Li			MW	T	WC			Ku	BM
Papillaria flavolimbata (Müll.Hal. & Hampe) A.Jaeger		S	La	WF	Ka			Bl	Mg	MV		N	MB	MW	T			Bi		
Papillaria flexicaulis (Wilson) A.Jaeger							C		Mg					MW	T					
Papillaria leuconeura (Müll.Hal.) A.Jaeger			La	WF	Ka			Bl	Mg	MV	Li	N	MB	MW	T			Bi		
Papillaria nitens (Hook.f. & Wilson) Sainsbury									Mg					MW	T					
Papillaria zeloflexicaulis Streimann			La					Bl	Mg		Li			MW	T			Bi		
Mniaceae																				
Plagiomnium novae-zealandiae (Colenso) T.J.Kop.			La				C		Mg						T	WC				
Pohlia cruda (Hedw.) Lindenb.																				BM
Pohlia nutans (Hedw.) Lindenb.			La		Ka			Bl									BC			
Schizymenium bryoides Harv. ex Hook.															T					
Mitteniaceae																				
Mittenia plumula (Mitt.) Lindb.			La	WF	Ka			Bl	Mg					MW	T					
Neckeraceae																				
Neckera pennata Hedw.				WF			C		Mg							WC		Bi	Ku	
Thamnobryum pandum (Hook.f. & Wilson) I.G.Stone & G.A.M.Scott														MW		WC				
Thamnobryum pumilum (Hook.f. & Wilson) Nieuwl.									Mg					MW						BM
Orthodontaceae																				

Family/Taxon	G	S	La	WF	Ka	KB	C	Bl	Mg	MV	Li	N	MB	MW	T	WC	BC	Bi	Ku	BM
†*Orthodontium inflatum* (Mitt.) Paris																				BM
Orthodontium lineare Schwägr.		S	La	WF	Ka	KB		Bl	Mg					MW	T					
†*Orthodontium pallens* (Hook.f. & Wilson) Broth.																				BM
Orthotrichaceae																				
Macrocoma tenuis (Hook. & Grev.) Vitt subsp. *tenuis*			La	WF	Ka		C	Bl	Mg		Li		MB	MW	T					
†*Macromitrium archeri* Mitt.			La	WF	Ka			Bl	Mg		Li			MW	T					
†*Macromitrium hemitrichodes* Schwägr.	G		La	WF	Ka			Bl	Mg				MB	MW	T	WC	BC		Ku	
Macromitrium involutifolium (Hook. & Grev.) Schwägr. subsp. *involutifolium*	G		La	WF				Bl						MW			BC		Ku	
Macromitrium involutifolium (Hook. & Grev.) Schwägr. subsp. *ptychomitrioides* (Besch.) Vitt & H.P.Ramsay	G		La	WF									MB	MW	T	WC	BC		Ku	
Macromitrium ligulaefolium Broth.		S	La	WF	Ka			Bl	Mg		Li			MW		WC			Ku	
Macromitrium ligulare Mitt.			La	WF	Ka		C	Bl	Mg					MW	T					
Macromitrium microstomum (Hook. & Grev.) Schwägr.		S	La	WF	Ka			Bl	Mg	MV	Li			MW					Ku	
†*Macromitrium repandum* Müll.Hal.			La	WF	Ka			Bl	Mg			N		MW	T					
Orthotrichum assimile Müll.Hal.		S		WF	Ka	KB			Mg					MW	T					
Orthotrichum tasmanicum Hook.f. & Wilson var. *tasmanicum*														MW						BM
Schlotheimia brownii Schwägr.				WF				Bl		MV										
Zygodon intermedius Bruch & Schimp.						KB								MW						
Plagiotheciaceae																				
Plagiothecium lamprostachys (Hampe) A.Jaeger				WF								N		MW						
Polytrichaceae																				
Atrichum androgynum (Müll.Hal.) A.Jaeger			La		Ka				Mg											
†*Dawsonia longiseta* Hampe	G		La				C													
†*Dawsonia polytrichoides* R.Br.	G	S	La	WF							Li	N		MW	T		BC		Ku	
Dawsonia superba Grev. var. *pulchra* Zanten								Bl						MW	T		BC			
Pogonatum neesii (Müll.Hal.) Dozy			La					Bl	Mg			N		MW			BC			
Pogonatum subulatum (Brid.) Brid.			La	WF	Ka	KB		Bl	Mg	MV				MW	T					
[c]*Polytrichastrum alpinum* (Hedw) G.L.Sm.				WF		KB														
# *Polytrichastrum formosum* (Hedw.) G.L.Sm.				WF																
[c]*Polytrichum commune* Hedw. var. *commune*			La	WF	Ka	KB		Bl	Mg		Li	N		MW	T					
[c]*Polytrichum juniperinum* Hedw.			La	WF	Ka	KB		Bl	Mg	MV	Li	N			T					
Pottiaceae																				
Acaulon integrifolium Müll.Hal.														MW						
Aloina aloides (Schultz) Kindb. var. *ambigua* (Bruch. & Schimp.) E.J.Craig									Mg											
Barbula calycina Schwägr.			La	WF		KB		Bl	Mg	MV	Li	N		MW	T		BC	Bi	Ku	
Barbula crinita Schultz			La	WF				Bl		MV	Li				T					
Barbula cf. *rehmannii*															T					
†*Barbula speirostega* Müll.Hal.			La																	

Barbula subcalycina Müll.Hal.		La																	
**Barbula unguiculata* Hedw.	S			Ka			Bl					MB		T					
Bryoerythrophyllum binnsii (R.Br. bis) Wijk & Margad.							Bl						MW						
Calyptopogon mnioides (Schwägr.) Broth.													MW						
Didymodon torquatus (Taylor) Catches.					KB				MV						WC				
ᶜ*Gymnostomum calcareum* Nees & Hornsch.		La					Bl												
Tetrapterum cylindricum (Taylor) A.Jaeger																			BM
Tortula antarctica (Hampe) Wilson													MW						
ᶜ*Tortula muralis* Hedw.		La	WF	Ka			Bl			Li		MB		T	WC				
Tortula pagorum (Milde) de Not.				Ka			Bl		MV				MW	T					
Tortula papillosa Wilson		La					Bl		MV				MW	T				Ku	
Tortula phaea (Hook.f. & Wilson) Dixon																			BM
†*Trachycarpidium brisbanicum* (Müll.Hal.) I.G.Stone														T					
**Trichostomum brachydontium* Bruch.			WF						MV										
Trichostomum eckelianum R.H. Zander						C			MV										
Triquetrella papillata (Hook.f. & Wilson) Broth.		La				C	Bl		MV	Li								Ku	
ᶜ*Weissia controversa* Hedw.		La	WF	Ka			Bl	Mg	MV	Li		MB		T		BC	Bi	Ku	
Pterobryaceae																			
Trachyloma diversinerve Hampe							Bl												
Trachyloma planifolium (Hedw.) Brid.							Bl										Bi		
Ptychomitriaceae																			
Ptychomitrium australe (Hampe) A.Jaeger				Ka		C	Bl					MB		T					
Ptychomitrium muelleri (Mitt.) A.Jaeger													MW						
Pytchomniaceae																			
Glyphothecium sciuroides (Hook.) Hampe								Mg											
Hampeella pallens (Sande Lac.) M.Fleisch.		La					Bl	Mg		Li	N		MW	T	WC				
Ptychomnion aciculare (Brid.) Mitt.		La	WF	Ka			Bl					MB	MW	T		BC			
Racopilaceae																			
Racopilum cuspidigerum (Schwägr) Ångstr. var. *convolutaceum* (Müll.Hal.) Zanten & Dijkstra	S						Bl	Mg	MV				MW			BC			
Racopilum cuspidigerum (Schwägr) Ångstr. var. *cuspidigerum*		La				C	Bl	Mg			N		MW	T	WC		Bi		
Rhacocarpaceae																			
Rhacocarpus purpurascens (Brid.) Paris	S	La	WF	Ka	KB		Bl	Mg	MV	Li	N	MB	MW	T		BC	Bi		
Rhizogoniaceae																			
Goniobryum subbasilare (Hook.) Lindb.													MW						
Hymenodon pilifer Hook.f. & Wilson													MW						
Leptotheca gaudichaudii Schwägr. var. *gaudichaudii*			WF		KB		Bl	Mg	MV		N		MW	T					
†*Mesochaete undulata* Lindb.		La	WF	Ka			Bl	Mg	MV				MW		WC		Bi	Ku	
Pyrrhobryum mnioides (Hook.) Manuel subsp. *contortum* (Wilson) Fife							Bl	Mg	MV				MW						

Pyrrhobryum paramattense (Müll.Hal.) Manuel		S	La	WF	Ka			Bl	Mg			N	MB	MW	T	WC	BC	Bi	Ku	
Pyrrhobryum spiniforme (Hedw.) Mitt.			La	WF	Ka			Bl							T					
Rhizogonium distichum (Sw.) Brid.				WF										MW						
Rhizogonium novae-hollandiae (Brid.) Brid.					Ka			Bl							T					BM
Rhizogonium pennatum Hook.f. & Wilson				WF	Ka									MW						
Family/Taxon	**G**	**S**	**La**	**WF**	**Ka**	**KB**	**C**	**Bl**	**Mg**	**MV**	**Li**	**N**	**MB**	**MW**	**T**	**WC**	**BC**	**Bi**	**Ku**	**BM**
Seligeriaceae																				
Blindia robusta Hampe				WF																BM
Sematophyllaceae																				
Rhaphidorrhynchium amoenum (Hedw.) M.Fleisch. var. *amoenum*			La		Ka			Bl	Mg						T		BC			
Sematophyllum homomallum (Hampe) Broth.			La				C											Bi		
Sematophyllum joliffii (Hook.f.) Dixon								Bl												
Sematophyllum subhumile (Müll.Hal.) M.Fleisch. var. *contiguum* (Mitt.) B.C.Tan				WF				Bl							T			Bi		
Sematophyllum subhumile (Müll.Hal.) M.Fleisch. var. *subhumile*		S	La	WF	Ka			Bl	Mg					MW						
Sematophyllum subpinnatum (Brid.) E.Britton				WF																
Sematophyllum uncinatum I.G.Stone & G.A.M.Scott					Ka			Bl												
†*Trichosteleum subfalcatulum* (Broth. & Watts) B.C.Tan, W.B.Schofield & H.P.Ramsay				WF																
#*Warburgiella macrospora* (Dixon & Sainsbury) B.C.Tan, W.B.Schofield & H.P.Ramsay														MW						
Wijkia extenuata (Brid.) H.A.Crum		S	La	WF	Ka			Bl	Mg	MV	Li	N	MB	MW	T	WC		Bi	Ku	BM
Sphagnaceae																				
Sphagnum australe Mitt.								Bl												
Sphagnum cristatum Hampe			La	WF	Ka	KB		Bl			Li			MW	T					
Sphagnum falcatulum Besch.								Bl												
Sphagnum novo-zelandicum Mitt.					Ka			Bl			Li									
Sphagnum perichaetiale Hampe								Bl												
Splachnaceae																				
Tayloria octoblepharum (Hook.) Mitt. var. *octoblepharum*	G		La	WF	Ka	KB		Bl		MV				MW				Bi		
Thuidiaceae																				
Thuidiopsis furfurosa (Hook.f. & Wilson) M.Fleisch.				WF				Bl												
Thuidiopsis sparsa (Hook.f. & Wilson) Broth.		S	La	WF	Ka		C	Bl	Mg	MV	Li	N		MW	T	WC		Bi		
Thuidium cymbifolium (Dozy & Molk.) Dozy & Molk.					Ka			Bl						MW	T				Ku	
Thuidium laeviusculum (Mitt.) A.Jaeger														MW						
Total number of taxa at each location	**14**	**29**	**95**	**104**	**78**	**32**	**28**	**131**	**75**	**44**	**41**	**41**	**32**	**120**	**89**	**33**	**34**	**38**	**28**	**20**

Table 4: Liverworts and Hornworts of the Blue Mountains Region

G = Glenbrook + Lapstone + Blaxland, S = Springwood + Valley Heights + Faulconbridge, La = Lawson + Woodford + Hazelbrook, WF = Wentworth Falls, Ka = Katoomba, KB = Kanangra-Boyd, C = Colong + Yerranderie, Bl = Blackheath, Mg = Megalong Valley, MV = Mount Victoria, Li = Lithgow + Clarence, N = Newnes Plateau, MB = Mt Banks + Pierces Pass, MW = Mount Wilson + Mount Irvine, T = Mount Tomah, WC = Wheeney Creek + Mountain Lagoon, BC = Bowens Creek, Bi = Bilpin, Ku = Kurrajong, BM = Blue Mountains (locality unknown).

New records for NSW (McCarthy 2003)

* Introduced species

Family/Taxon	**G**	**S**	**La**	**WF**	**Ka**	**KB**	**C**	**Bl**	**Mg**	**MV**	**Li**	**N**	**MB**	**MW**	**T**	**WC**	**BC**	**Bi**	**Ku**	**BM**
Acrobolbaceae																				
Enigmella thallina G.A.M.Scott & K.G.Beckm.													MB							
Goebelobryum unguiculatum (Hook.f. & Taylor) Grolle			La	WF				Bl					MB	MW			BC			
Lethocolea pansa (Taylor) G.A.M.Scott & K.G.Beckm.			La	WF				Bl	Mg			N	MB				BC	Bi		
Marsupidium surculosum (Nees) Schiffn.								Bl	Mg											
Tylimanthus diversifolius E.A.Hodgs.								Bl												
Tylimanthus tenellus (Hook.f. & Taylor) Mitt.					Ka										T					
Aneuraceae																				
Aneura alterniloba (Hook.f. & Taylor) Taylor & Hook.f. var. *alterniloba*			La	WF				Bl			Li						BC			
Aneura alterniloba (Hook.f. & Taylor) Taylor & Hook.f. var. *gigantea* (Steph.) Hewson			La	WF				Bl					MB				BC	Bi		
Aneura rodwayi Hewson			La	WF																
Riccardia aequicellularis (Steph.) Hewson			La	WF	Ka			Bl						MW						
Riccardia bipinnatifida (Colenso) Hewson			La		Ka			Bl						MW						
Riccardia cochleata (Hook.f. & Taylor) Kuntze			La					Bl												
Riccardia colensoi (Steph.) W.Martin								Bl		MV		N		MW		WC				
Riccardia crassa (Schwägr.) Carrington & Pearson		S	La	WF	Ka			Bl		MV		N	MB	MW			BC	Bi		
Riccardia graeffei (Steph.) Hewson								Bl												
Riccardia lobulata (Colenso) E.A.Hodgs.								Bl												
Riccardia rupicola (Steph.) Hewson			La					Bl		MV				MW				Bi		
Anthocerotaceae (Hornworts)																				
Anthoceros punctatus L.							C						MB							
Megaceros gracilis (Rchdt.) Steph.							C	Bl	Mg					MW	T					
Phaeoceros carolinianus (Michx.) Prosk.			La	WF			C	Bl						MW			BC		Ku	
Aytoniaceae																				
Asterella drummondii (Hook.f. & Taylor) R.M.Schust. ex D.G.Long														MW						
Plagiochasma rupestre (J.R.Forst. & G.Forst.) Stephani							C							MW						
Reboulia hemisphaerica (L.) Raddi			La	WF			C		Mg					MW		WC				BM

Family/Taxon	G	S	La	WF	Ka	KB	C	Bl	Mg	MV	Li	N	MB	MW	T	WC	BC	Bi	Ku	BM
Balantiopsidaceae																				
Balantiopsis diplophylla (Hook.f. & Taylor) Mitt.		S	La	WF	Ka			Bl		MV		N	MB	MW	T	WC		Bi		
Balantiopsis tumida Berggr.																		Bi		
Isotachis grandis Carrington & Pearson			La					Bl												
Isotachis intortifolia (Hook.f. & Taylor) Gottsche			La	WF				Bl				N		MW						
Cephaloziellaceae																				
Cephaloziella exiliflora (Taylor) Douin			La				C	Bl							T	WC				
Cephaloziella hirta (Steph.) R.M.Schust.											Li									
Cephaloziella varians (Gottsche) Steph.												N								
Chaetophyllopsidaceae																				
Chaetophyllopsis whiteleggei (Carrington & Pearson) R.M.Schust.				WF																
Fossombroniaceae																				
Fossombronia pusilla (L.) Nees				WF					Mg					MW					Ku	
Fossombronia wondraczekii (Corda) Dumort. ex Lindenb.														MW						
Geocalycaceae																				
Chiloscyphus glaucescens Steph.				WF																
Chiloscyphus latifolius (Nees) J.J.Engel							C													
Chiloscyphus multipennus (Hook.f. & Taylor) J.J.Engel & R.M.Schust									Mg											
Chiloscyphus semiteres (Lehm. & Lindenb.) Lehm. & Lindenb.			La	WF		KB	C	Bl				N		MW	T	WC	BC	Bi		
Geocalyx caledonicus Steph.								Bl												
Heteroscyphus argutus (Reinw., Blume & Nees) Schiffn.			La						Mg			N		MW	T		BC			
Heteroscyphus biciliatus (Hook.f. & Taylor) J.J.Engel														MW						
Heteroscyphus cambewarranus (Steph.) J.J.Engel & R.M.Schust.														MW						
Heteroscyphus coalitus (Hook.) Schiffn.								Bl				N								
Heteroscyphus fissistipus (Hook.f. & Taylor) Schiffn.	G				Ka			Bl	Mg					MW			BC			
Heteroscyphus limosus (Carrington & Pearson) Schiffn.								Bl	Mg							WC		Bi		
Leptoscyphus expansus (Lehm.) Grolle								Bl												
Haplomitriaceae																				
Haplomitrium intermedium Berrie			La														BC			
Hymenophytaceae																				
Hymenophyton flabellatum (Labill.) Dumort. ex Trevis.				WF				Bl					MB	MW	T	WC	BC	Bi		
Jackiellaceae																				
Jackiella curvata E.A.Hodgs. & Allison				WF																

Jubulaceae																
# *Frullania allanii* E.A.Hodgs.			WF													
Frullania cataractarum Steph.														BC		
Frullania clavata (Hook.f. & Taylor) Taylor ex Gottsche, Lindenb. & Nees						Bl	Mg				MW	T				
Frullania falciloba Taylor ex Lehm.					C	Bl	Mg				MW	T				
Frullania monocera (Hook.f. & Taylor) Taylor ex Gottsche, Lindenb. & Nees var. *monocera*		La	WF		C	Bl					MW	T		BC		
Frullania pentapleura Taylor					C							T				
Frullania probosciphora Taylor					C							T				
Frullania aff. *rostrata*		La														
Frullania rostrata (Hook.f. & Taylor) Taylor ex Gottsche, Lindenb. & Nees		La	WF			Bl			N	MB	MW			BC	Bi	
Frullania rubella Gottsche ex Steph. var. *rubella*				Ka												
Frullania squarrosula (Hook.f. & Taylor) Taylor ex Gottsche, Lindenb. & Nees	S	La		Ka	C	Bl					MW	T				
Jungermanniaceae																
Cryptochila grandiflora (Lindenb. & Gottsche) Grolle																BM
Cryptochila nigrescens (Steph.) Grolle		La														
Solenostoma inundatum (Hook.f. & Taylor) Mitt. ex Steph.						Bl					MW					
Lejeuneaceae																
Acrolejeunea securifolia (Nees) Steph. & Watts																BM
Cheilolejeunea mimosa (Hook.f. & Taylor) R.M. Schust.		La					Mg						WC			
Diplasiolejeunea plicatiloba (Hook.f. & Taylor) Grolle			WF													
Lejeunea drummondii Taylor					C		Mg		N			T		BC		
Lepidoziaceae																
Acromastigum furcatifolia (Steph.) E.A.Br. ms		La								MB					Bi	
Acromastigum colensoanum (Mitt.) A.Evans ex Reimers						Bl	Mg				MW					
Acromastigum exiguum (Steph.) A.Evans		La				Bl	Mg						WC		Bi	
Bazzania involuta (Mont.) Trevis.		La	WF			Bl	Mg		N	MB			WC	BC	Bi	
Bazzania monilinervis (Lehm. & Lindenb.) Trevis.								MV							Bi	
Bazzania wattsiana (Steph.) comb. nov.													WC			
# *Drucella integristipula* (Steph.) E.A.Hodgs.													BC			
Hygrolembidium acrocladum (Berggr.) R.M.Schust.			WF													
Kurzia compacta (Steph.) Grolle		La	WF			Bl	Mg	MV	N	MB				BC	Bi	
Kurzia calcarata (Steph.) Grolle						Bl										
Kurzia dendroides (Carrington & Pearson) Grolle				Ka		Bl				MB						
Kurzia hippurioides (Hook.f. & Taylor) Grolle	S	La	WF			Bl	Mg		N	MB	MW	T	WC	BC	Bi	
# *Kurzia tenuoides* R.M. Schust.														BC		
Lepidozia asymmetrica Steph.						Bl										
Lepidozia laevifolia (Hook.f. & Taylor) Taylor ex Gottsche, Lindenb. & Nees var. *laevifolia*		La	WF	Ka		Bl				MB	MW	T		BC	Bi	

Family/Taxon	G	S	La	WF	Ka	KB	C	Bl	Mg	MV	Li	N	MB	MW	T	WC	BC	Bi	Ku	BM
# *Lepidozia procera* Mitt.			La	WF																
Lepidozia quadrifida Kunze ex Lindenb.			La																	
Lepidozia quadristipula Steph.								Bl												
Lepidozia ulothrix (Schwägr.) Lindenb.			La	WF	Ka			Bl	Mg	MV		N	MB	MW			BC	Bi		
Lepidozia wattsiana Steph.																WC				BM
Paracromastigum longiscyphum (Taylor) R.M.Schust. & J.J.Engel			La	WF													BC			
# *Psiloclada clandestina* Mitt. subsp. *clandestina*													MB				BC			
Telaranea capilligera (Schwägr.) R.M.Schust.				WF				Bl												
Telaranea elegans (Colenso) J.J.Engelo & G.L.Sm.		S	La	WF	Ka			Bl	Mg	MV	Li	N	MB	MW			BC	Bi		
Telaranea quinquespina (J.J.Engel & G.L.Sm.) J.J.Engel & G.L.Sm.																	BC			
Telaranea tetradactyla (Hook.f. & Taylor) E.A.Hodgs.			La					Bl												
Zoopsis argentea (Hook.f. & Taylor) Taylor ex Gottsche, Lindenb. & Nees			La					Bl	Mg				MB					Bi		
Zoopsis leitgebiana (Carrington & Pearson) Bastow		S	La	WF	Ka			Bl		MV		N		MW				Bi		
Zoopsis setulosa Leitg.		S	La	WF	Ka			Bl	Mg			N	MB	MW		WC		Bi		
Lunulariaceae																				
**Lunularia cruciata* (L.) Dumort.				WF			C	Bl	Mg					MW	T					
Marchantiaceae																				
Marchantia berteroana Lehm. & Lindenb.								Bl				N		MW						
Marchantia polymorpha L. var. *aquatica* Nees		S		WF							Li			MW	T					
Metzgeriaceae																				
Metzgeria furcata (L.) Dumort.			La	WF	Ka			Bl				N		MW	T	WC	BC			
Metzgeria leptoneura Spruce					Ka			Bl												
# *Metzgeria submarginata* So								Bl												
Pallaviciniaceae																				
Jensenia connivens (Colenso) Grolle				WF																
Pallavicinia lyellii (Hook.) Grey			La	WF				Bl									BC	Bi		
Pallavicinia purpurea Steph.				WF																
Pallavicinia xiphoides (Hook.f. & Taylor) Trevis.					Ka															
Podomitrium phyllanthus (Hook.) Mitt.			La	WF				Bl				N	MB							
Symphyogyna interrupta Carrington & Pearson			La					Bl	Mg					MW						
Symphyogyna multiflora Steph.				WF																
Symphyogyna podophylla (Thunb.) Mont. & Nees			La	WF				Bl	Mg			N	MB	MW	T		BC	Bi		
Plagiochilaceae																				
# *Plagiochila arbuscula* (Brid. ex Lehm. & Lindenb.) Lindenb.			La																	
Plagiochila baileyana Steph.								Bl	Mg											
Plagiochila fasciculata Lindenb.			La	WF				Bl	Mg					MW			BC			
Plagiochila strombifolia Taylor ex Lehm.								Bl	Mg											

Porellaceae																				
Porella crawfordii Steph.							C	Bl						MW	T	WC	BC			
Radulaceae																				
Radula acutiloba Steph.														MW						
Radula buccinifera (Hook.f. & Taylor) Taylor ex Gottsche, Lindenb. & Nees		S	La					Bl		MV				MW			BC	Bi		
Radula pulchella Mitt. ex Steph.																	BC			
Radula wattsiana Steph.								Bl												
Ricciaceae																				
Riccia bifurca Hoffm.																			Ku	
Riccia crinita Taylor																			Ku	
Riccia papulosa (Steph.) Steph. var. *papulosa*																			Ku	
Trichocoleaceae																				
Trichocolea mollissima (Hook.f. & Taylor) Gottsche								Bl						MW					Ku	
# *Trichocolea rigida* R.M.Schust.			La						Mg				MB	MW		WC		Bl		
Total number of taxa at each location	**1**	**9**	**49**	**43**	**17**	**1**	**16**	**66**	**29**	**10**	**4**	**22**	**23**	**46**	**21**	**17**	**33**	**26**	**6**	**4**

Comparison with published bryophyte records

The 225 moss taxa of the Blue Mountains reported here make up nearly half (43%) of the 527 moss taxa recorded for New South Wales in Ramsay's (1984) *Census of New South Wales Mosses*. Comparison with regional species numbers from Ramsay is difficult, as our study area includes sections of both the Central Tablelands and Central Coast Botanical Subdivisions. However, 159 moss taxa listed by Ramsay for the Central Tablelands Botanical Subdivision, which includes the greater part of our survey area, were recorded in this study, together with an additional 45 taxa not listed by Ramsay.

175 of the 247 moss taxa listed by Ramsay and Selkirk for the Blue Mountains World Heritage Listing assessment (James 1994) were recorded in this study, plus a further 52 taxa. Of the 71 taxa on Ramsay and Selkirk's list not recorded in this study, many, such as *Gigaspermum repens* (Hook.) Lindb., *Encalypta vulgaris* Hedw. and species of Bryaceae and Pottiaceae, are likely to have been collected on the Jenolan and Wombeyan Caves limestones, which are known to have a unique and diverse bryophyte assemblage (Downing 1992; Downing, Ramsay & Schofield 1991, Downing, Oldfield & Selkirk 1995). Others such as *Echinodium hispidum* (Hook.f. & Wilson) Reichardt and *Rhodobryum aubertii* (Schwägr.) Thér. are likely to have come from the lower altitude closed forests of Nattai or Dharug National Parks. Both areas are outside our Blue Mountains study area.

Of a total of 122 liverwort taxa listed by Ramsay & Selkirk (James 1994), 82 were recorded in this study, together with an additional 43 species. Of the 40 species not recorded in this study, some species such as *Targionia hypophylla* L. and *Riccia limbata* Bisch. commonly occur on limestone and are likely to have been collected at Jenolan or Wombeyan. Other taxa listed by Ramsay & Selkirk, such as *Mastigobryum dentistipulum* and *M. gracillimum* have since been transferred to other taxa.

We have been able to add 26 moss taxa to Ramsay, Downing & Schofield's (1990) list for Mount Tomah Botanic Gardens, increasing the total number of bryophyte taxa there to 110. The number of liverwort species has decreased by one (*Metzgeria decipiens* is now synonymous with *M. furcata*).

Bryophyte collection difficulties

Information for this study has been gleaned from many sources rather than from a single field investigation and there are some problems with information (or the lack of it) on specimen packets. In some cases, the location has been given simply as *Blue Mountains* (included in Tables 3 and 4 as 'Blue Mountains').We have excluded from our species list some specimens (held in MEL) collected by Ferdinand von Mueller about 1855, supposedly from the *Blue Mountains*, but unlikely to have been collected within our definition of the Blue Mountains region. It is likely that they were collected in the Southern Alps near Mount Kosciuszko, at that time perhaps seen as a southern extension of the Blue Mountains. Most are accepted as alpine species and have been listed by Ramsay *et al.* (1986) as occurring in the alpine areas of New South Wales above 1800 m elevation. The species are: *Aulacomnium palustre* (Hedw.) Schwägr., *Blindia robusta* Hampe, *Bryum australe* Hampe, *Catagonium nitens* (Brid.) Cardot, *Entosthodon apophysatus* (Taylor) Mitt., *Lepyrodon pseudoalgurus* B.H.Allen, *Notoligotrichum crispulum* (Hook.f. & Wilson) G.M.Sm., *Physcomitrium conicum* Mitt., *Polytrichastrum alpinum* (Hedw.) G.L.Sm. and *Sanionia uncinata* (Hedw.) Loeske. Only two of these species collected by von Mueller, *Polytrichastrum alpinum* and *Blindia robusta,* have since been recorded from the Blue Mountains.

Polytrichastrum alpinum has been recorded from Kanangra Boyd National Park, above 1000 m a.s.l., (by J. Glime in 1981) and at Wentworth Falls (by H. Ramsay in 1977). This species has also been recorded from the summit of Mount Canobolas, 1395 m a.s.l., 130 km north-west of Katoomba (Downing, Oldfield & Fairburn-Wilson 2002), making its presence in the higher areas of the Blue Mountains not surprising.

Blindia robusta is a conspicuous species and there are two specimens (in the John Ray Herbarium, University of Sydney (SYD)) collected in 1930 at Wentworth Falls by A. Burges. There are a number of other moss specimens collected by Burges at Wentworth Falls on the same date, and as these species still commonly occur in the vicinity of Wentworth Falls, it is apparent that Burges did collect *B. robusta* from this location. It is difficult to imagine how its occurrence along stream banks would have been overlooked by both earlier and later collectors. We have been unable to find it anywhere in the Blue Mountains and it may have been destroyed by drought, fire or urban development.

Habitat and ecological information on bryophytes is generally very limited. Many herbarium packets (although appropriately labelled with location) bear minimal information describing landform (plateau, ridge, valley, and canyon), aspect, moisture or lack of it, vegetation type (heath, woodland, forest, and closed forest), degree of shading, substrate (rock, soil or sand, tree trunk, tree branches, tree fern, fallen log), underlying rock (sandstone, shale, basalt, limestone, and granodiorite) or associated bryophytes. Such specimens have contributed to species lists for locations, but could not contribute information concerning habitat.

Other problems relate to identification. In the case of taxa that have been viewed by experts in recent years, it is possible to be confident in the names allocated to specimens, e.g. *Macromitrium* specimens determined by Vitt & Ramsay, *Papillaria* determined by H. Streimann, *Sphagnum* by R. Seppelt and *Aneura* and *Riccardia* determined by H. Hewson. However, there are many groups, such as *Campylopus, Grimmia* and *Leucobryum*, for which identification is challenging. Often there are no recent publications and it is not within the scope of this study to check the determinations of all the specimens held in various herbaria.

Discussion

The effect of accessibility on bryophyte recording

There was a considerable difference in the number of species recorded at different locations (Table 5) and accessibility has probably been the major factor determining the number of species recorded from some locations. Following construction of the railway in 1868, visitors were able to travel by train to Lawson, Wentworth Falls and Blackheath (Valder 1988). Govetts Leap (at Blackheath) and Wentworth Falls were the most popular Blue Mountains destinations, according to The Railway Guide of the day. Cheap train fares and a growth in tourist facilities attracted many visitors. Construction of walking tracks at Wentworth Falls and Govetts Leap began in 1890. By 1910, motor coaches facilitated travel from the railway to more distant locations (Burke 1988). In 1875, when the Mount Wilson Railway Station (later changed to Bell) was completed, it became much easier to travel to Mount Wilson and Mount Irvine (Valder 1988).

The early collectors, Whitelegge, Forsyth and Watts, all used rail and their collections, for example from Grand Canyon at Blackheath, from Valley of the Waters at Wentworth Falls, from Dantes Glen at Lawson, all indicate they used the same walking paths that we use today. The Rev. W.W. Watts walked or travelled on horseback to visit parishioners (Ramsay 1980) but today we still use the same road that Watts used, winding through closed forest from Mount Wilson to Mount Irvine.

Factors affecting distribution of bryophytes in the Blue Mountains: topography and geology

Most of the bryophytes in the Blue Mountains are found in the closed forests of gullies and valleys on sandstone and shale. The dense canopies of closed forests protect bryophytes from high light, extreme temperatures and desiccation by strong winds. Damp rocks, soil, fallen logs and tree roots are often covered with bryophytes. Unlike many eucalypts, trees of the closed forest, such as *Doryphora sassafras, Ceratopetalum apetalum* and *Callicoma serratifolia* have persistent bark, allowing epiphytic bryophytes to colonise tree trunks, branches and twigs. Bryophytes that can survive in low light levels of closed forest are often large and conspicuous, with growth forms that allow them to access maximum light levels. For example, pendulous mosses (*Papillaria* spp.) hang from tree trunks and tree fern trunks, and dendroid mosses and liverworts (*Hypnodendron vitiense* subsp. *australe, Hypopterygium* spp. and *Hymenophyton flabellatum)* grow upwards from wet rocks and soil along creek banks (Figures 4, 5). Tall, upright species, such as *Dawsonia superba* (Figure 12) rapidly colonise newly exposed earth of land slips, or gaping holes in the ground where mature trees have fallen. Three beautiful mosses, *Neckera pennata, Cyathophorum bulbosum* and *Calomnion complanatum* grow on the trunks of tree ferns, tree trunks and wet rocks, almost always in deep shade close to streams.

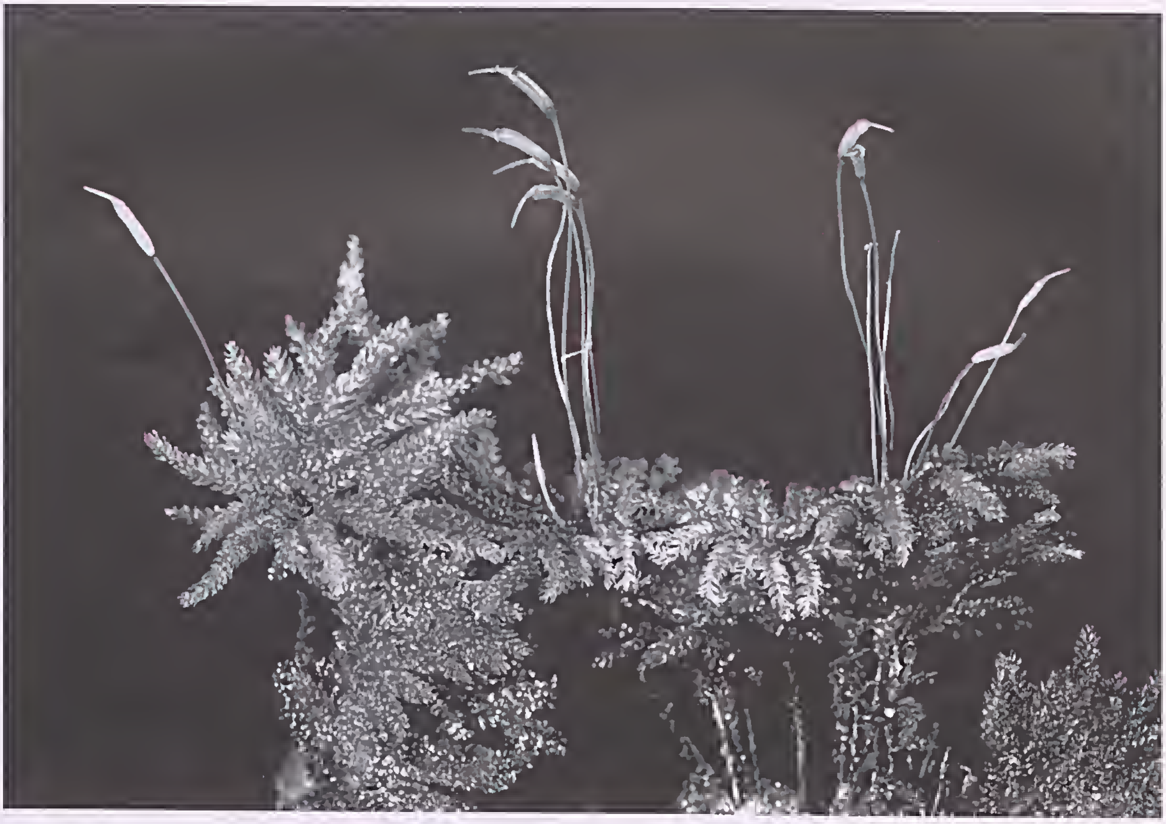

Fig. 4. Capsules of the dendroid moss, *Hypnodendron vitiense* subsp. *australe* are held on long setae above the branches. *Hypnodendron* is abundant on wet rock in and along creek beds in closed forest.

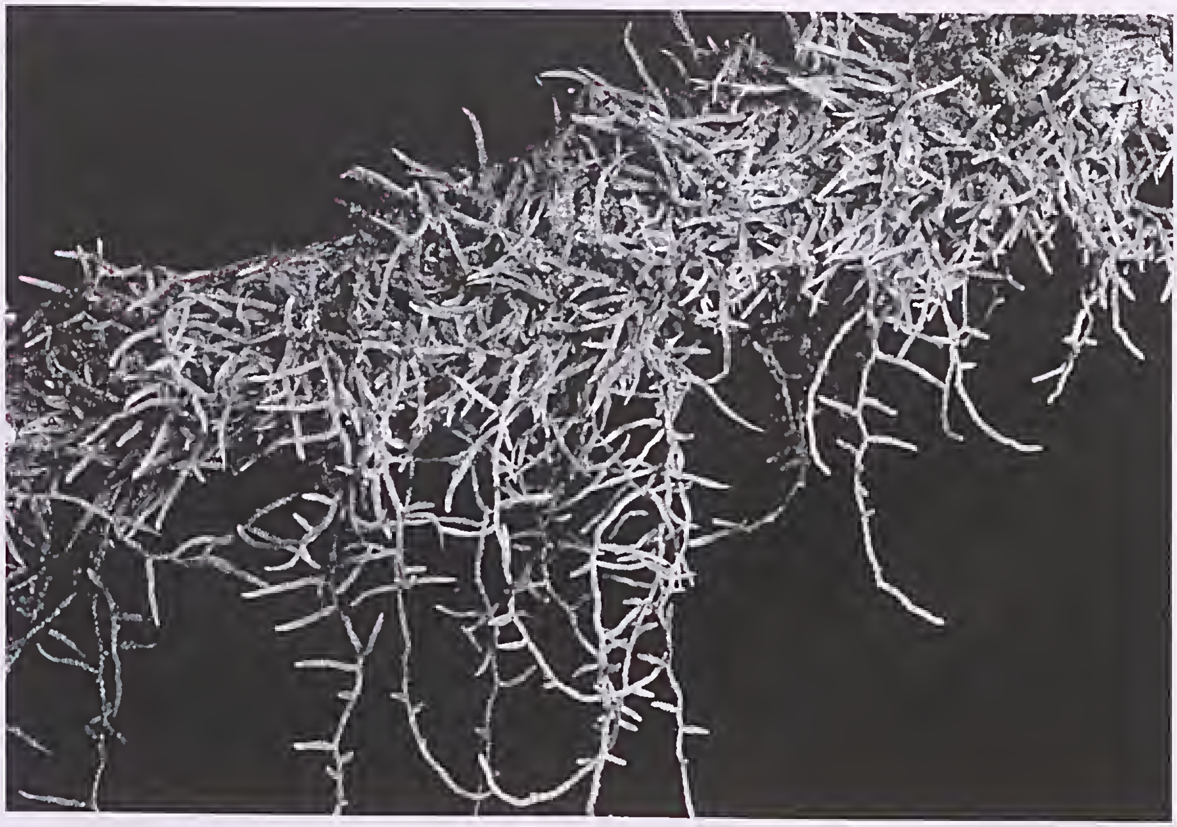

Fig. 5. *Papillaria* spp. festoon the branches of trees and shrubs along the edges of closed forest beside the Mount Wilson to Mount Irvine Road.

Cyathophorum bulbosum has long, unbranched stems, up to 10 cm long and can easily be mistaken for a fern.

In deep slot canyons, liverworts dominate the bryoflora, including thallose *Aneura alterniloba*, *Riccardia* spp., *Pallavicinia* spp. and *Symphyogyna* spp. and leafy liverworts, such as *Kurzia* spp., *Lepidozia* spp. and *Zoopsis* spp.

The upper branches of the rainforest canopy are also utilised by many bryophytes; these have different requirements from those of the forest floor. Gradients of light and humidity determine the number and type of species present in rainforests. Approaching the forest crown, humidity decreases and temperature and light levels increase (Ramsay, Streimann & Harden 1987) and a different assemblage of bryophytes survives these relatively harsh conditions, including *Macromitrium* spp., *Leptostomum* spp. and some Pottiaceae (e.g. *Tortula pagorum*, *Tortula papillosa* and *Calyptopogon mnioides)*.

In the forests and closed forests of the valley sides, mosses such as *Dicranoloma billarderi*, *Leucobryum candidum*, *Rhaphidorrhynchium amoenum* and *Sclerodontium pallidum* dominate the upper levels, while liverworts, such as *Balantiopsis diplophylla*, *Bazzania involuta* and*Symphyogyna podophylla* are more conspicuous at lower levels.

Few bryophyte species grow in the harsh conditions on the sandstone plateaus and ridges. The sandy soils and sandstone rock are both nutrient poor and freely draining, retaining little moisture. In *Eucalyptus* woodland, bryophytes are exposed to high light intensity, extremes of temperature, desiccation from drying winds, and bushfires. Most species survive in niches e.g. under logs, or where rocks provide protection from direct sunlight and wind. Shallow depressions on flat sheets of sandstone often hold water and decomposing leaf litter. Roadside and trackside banks and gutters provide shade and moisture.

The bryophytes that do occur on the plateau and ridge tops often occur abundantly and cover large areas of rock and sandy soil, e.g. the mosses *Campylopus clavatus*, *Campylopus flindersii*, *Campylopus introflexus* and *Campylopus pyriformis* and liverwort *Chiloscyphus semiteres* (Figure 7). *Cephaloziella exiliflora* can often be found in charcoal on burnt logs. *Rhacocarpus purpurascens*, *Breutelia* spp. and *Riccardia* spp. can be abundant in seepage areas, such as roadside and trackside drains, or on sandstone cliffs, often associated with ferns and epacrids (Figure 8). Surprisingly, the presence of few bryophyte species on sandstone ridges and plateaus is usually an indication of an undisturbed natural environment. Disturbed areas are likely to have a much greater diversity of bryophytes, including many introduced or cosmopolitan species.

The changes in bryophyte distribution from plateau to canyon have been well documented by Selkirk, Adamson & Downing (2001) (Table 2, Figure 6).

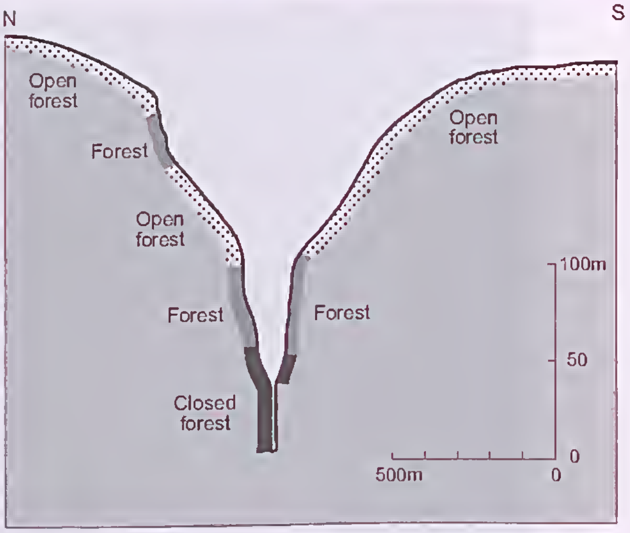

Fig. 6. Section across Greaves Creek, Blackheath, showing vegetation on plateau surface and valley sides. (modified after Selkirk, Adamson & Downing 2001).

Basalt caps

Most of the bryophytes that grow in closed forests in shale and sandstone gullies also occur on the basalt caps, where the combination of high rainfall, nutrient rich soils and abundant soil moisture support tall forests of *Eucalyptus fastigata* on the tops of basalt outcrops, and rainforest trees such as *Doryphora sassafras*, *Ceratopetalum apetalum*, *Acacia melanoxylon* and *Acmena smithii* on south and east-facing slopes. The establishment of gardens and small farms at Mount Tomah, Mount Wilson and Mount Irvine, has also influenced the bryophyte assemblages. Epiphytic mosses and liverworts are abundant, both on the trunks of exotic trees, such as *Aesculus* sp. (chestnut) and *Platanus* sp. (London Plane), and on native rainforest trees.

Granodiorites of Kanangra/Boyd

At Boyd River Crossing on the Jenolan Caves to Kanangra Walls Road, bryophytes are abundant on broad, open areas of granodiorite fringed with low heath which in turn is bordered by low *Eucalyptus* woodland. *Sphagnum cristatum* is plentiful along creek banks, *Conostomum pusillum*, *Racomitrium crispulum*, *Racomitrium pruinosum* and *Rhacocarpus purpurascens* form dense mats on the flat rock exposures. *Grimmia* spp. grow on small rocks. Large boulders scattered throughout the woodland are covered in dense mats of *Eucamptodon muelleri*, *Hedwigia ciliata*, *Hedwigidium integrifolium*, *Hypnum cupressiforme* and *Sclerodontium pallidum*. *Polytrichastrum alpinum*, *Polytrichum commune* and *Polytrichum juniperinum* are common in deep roadside soil. This is the highest area (> 1100 m a.s.l.) in this study and there is a clearly defined alpine element to the local species, with 21 of the 32 species of mosses recorded at Kanangra-Boyd listed as occurring in alpine areas (Ramsay *et al.* 1986).

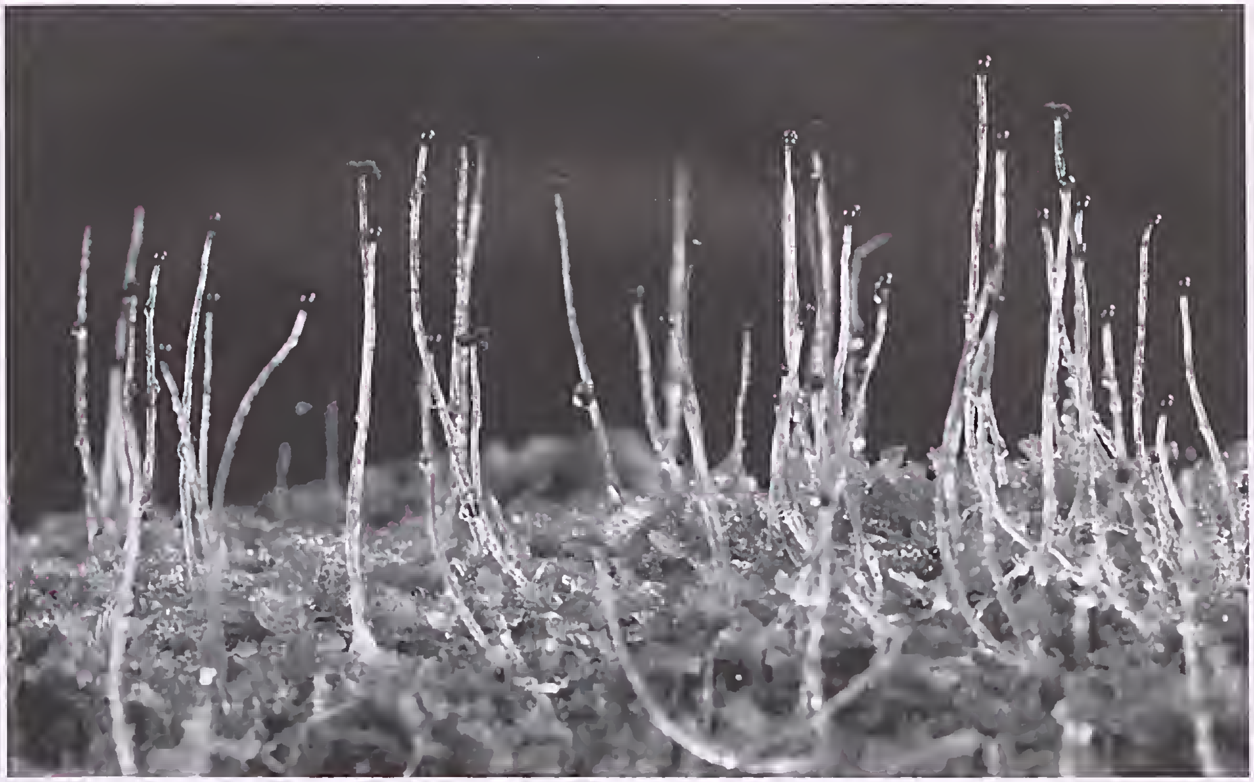

Fig. 7. *Chiloscyphus semiteres* can cover large areas of soil, rock and fallen logs. The delicate, translucent setae hold the black capsules above the leaves. Some have opened to release the spores. This is probably the most commonly occurring leafy liverwort in the Blue Mountains.

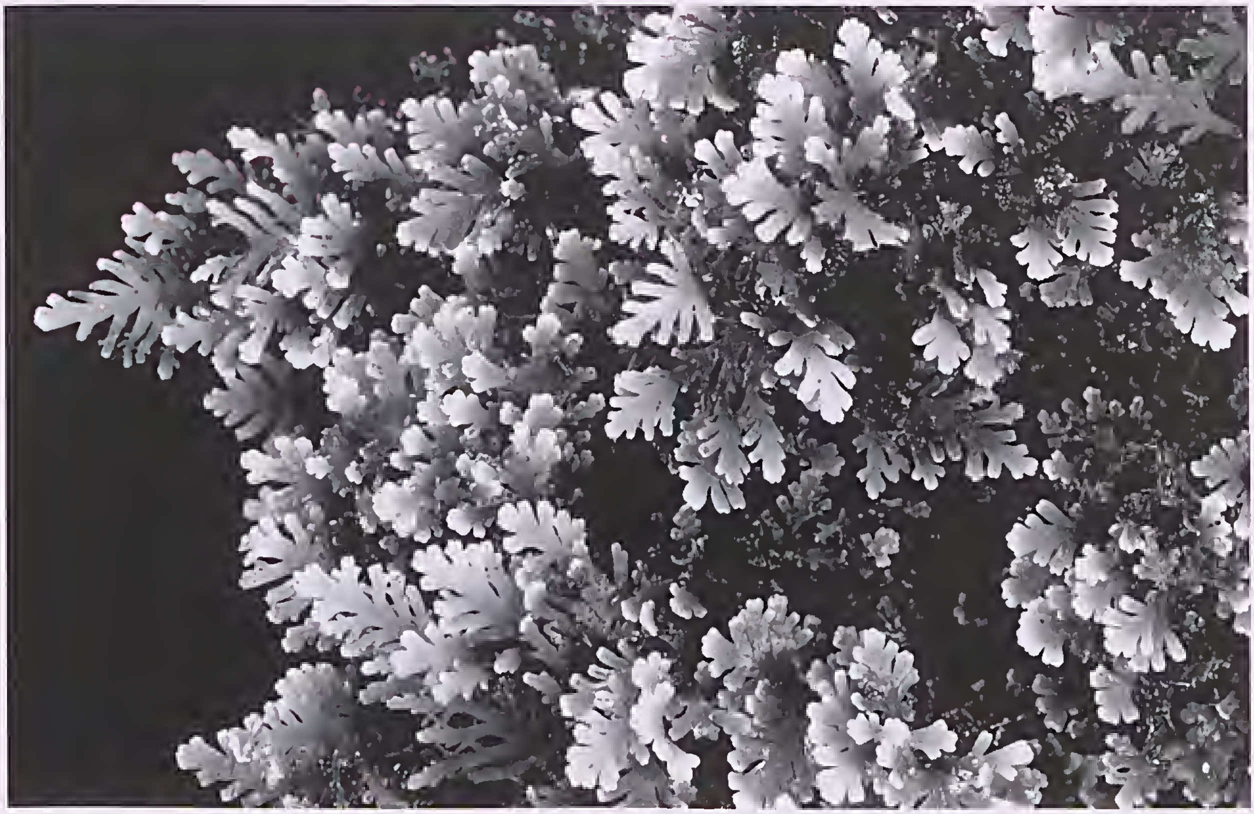

Fig. 8. The thallose liverwort *Riccardia crassa* is common along creeks, in roadside and trackside drains.

Colong limestones

At Colong, Silurian limestone lenses are dispersed through the slate and quartzite of the southern end of Kanangra-Boyd National Park. The bryophyte assemblage at Colong is typical of those found on other south-eastern Australian limestone deposits (Downing 1992).

Bryophytes and fire

Adam (1994) considered that refugia suitable for vascular rainforest plant species were characterised by the presence of water and protection from fire. In the Blue Mountains, sites with these characteristics also protect many species of bryophytes found in closed forest, such as *Achrophyllum dentatum, Dicranoloma* spp., *Hymenophyton flabellatum, Hypnodendron vitiense* subsp. *australe, Hypopterygium tamarisci, Isotachis intortifolia, Pyrrhobryum* spp. and *Riccardia* spp. Some species, such as ^c^*Funaria hygrometrica,* ^c^*Ceratodon purpureus* and ^c^*Polytrichum juniperinum* are known to rapidly colonise newly burnt areas in mixed forest in southern Tasmania (Duncan & Dalton 1982) and we have observed similar colonisation in *Eucalyptus* forests and woodlands in the Blue Mountains.

Frequently recorded bryophyte species

- The moss *Sclerodontium pallidum* occurred at every location in this study, growing in abundance on sandstone outcrops and boulders usually on hillsides.
- There were more records of *Wijkia extenuata* than any other rainforest moss, possibly because of its extreme variability.
- Many rainforest bryophytes are large and conspicuous, and these may be important factors in explaining their abundance in collections. They include the dendroid (tree-like) mosses *Hypnodendron vitiense* subsp. *australe*, *Hypopterygium tamarisci* and *Lopidium concinnum,* pendulous mosses, such as *apillaria* spp., and the milky green cushions and stems of *Leucobryum candidum* (Figure 4).
- Some mosses that thrive in disturbed areas such as roadside and trackside banks, are surprisingly common and occur at many locations. They include *Barbula calycina,* ^c^*Ceratodon purpureus, Ditrichum difficile,* ^c^*Polytrichum juniperinum, Rosulabryum billarderi* and ^c^*Weissia controversa.*
- *Telaranea elegans* (formerly *Telaranea centipes*) was collected at more locations than any other liverwort species, closely followed by *Balantiopsis diplophylla* and *Kurzia hippuroides.* All three are attractive and conspicuous.
- *Chiloscyphus semiteres* is probably the most commonly occurring liverwort on sandstone and shale of plateaus and ridges. It is easy to identify, but is not particularly appealing and is likely to have been overlooked by collectors (Figure 7).
- Hornwort species are neither numerous nor abundant in the Blue Mountains.

Alpine zone mosses in the Blue Mountains

There are a number of mosses in the Blue Mountains (44 taxa) that are also listed by Ramsay *et al.* (1986) as occurring in alpine areas above 1800 m a.s.l. For example *Andreaea subulata* and *Andreaea mutabilis, Bartramia ithyphylla, Blindia robusta, Conostomum pusillum, Polytrichastrum alpinum, Racomitrium crispulum* and *Racomitrium pruinosum* commonly occur at high altitude in Kosciuszko National Park. In the Blue Mountains these species grow on higher parts of the plateau, including Wentworth Falls, Katoomba, Blackheath and at Boyd River Crossing in Kanangra-Boyd National Park (Figure 9). Surprisingly, in addition to growing on sandstones of the plateau top at Wentworth Falls and Katoomba, *Andreaea subulata* and *Andreaea mutabilis* can be found on sandstone boulders deep in the Greaves Creek valley just below Grand Canyon at Blackheath. Recently they have been found in a deep gully in the Grampians in north-western Victoria (D. Meagher, pers. comm.).

Arid zone mosses in the Blue Mountains

In the western areas of the Blue Mountains, in particular at Mount York (6 km west of Mount Victoria) and Blackheath, bryophyte assemblages on compacted soils of lookouts, public parks and gardens, often include species that are more usually associated with the microphytic soil crusts in more arid areas of Australia. These include Pottiaceae (e.g. *Aloina aloides* var. *ambigua, Barbula calycina, Barbula crinita, Didymodon torquatus, Triquetrella papillata* and *Weissia controversa*) and Bryaceae (for example *Bryum argenteum, Gemmabryum dichotomum, Gemmabryum eremaeum* and *Gemmabryum pachytheca*). Their presence at these sites in the Blue Mountains is a matter for conjecture. Propagules may have been carried by dust storms originating in the arid zone of far western New South Wales and deposited on the western fringes of the Blue Mountains. Stock movements may also have contributed to the spread of propagules. From the time William Cox and his convicts completed the first road over the Blue Mountains in 1815, until the completion of the railway line in 1869 to Bowenfels just west of Lithgow, the road from Hampton to Mount Victoria and Blackheath was the route by which sheep and cattle were moved from the western plains to the Sydney markets (Low 1988).

Calciphile bryophytes in the Blue Mountains

Very distinct assemblages of bryophytes grow on calcareous soils throughout the world, and in south-eastern Australia, more bryophyte species are found on calcareous substrates than on non-calcareous substrates. The assemblage is always dominated by mosses from the Pottiaceae and Bryaceae, and by thallose liverworts from the Marchantiales (Downing 1992).

The limestones at Colong Caves include calciphile mosses *Gymnostomum calcareum, Trichostomum eckelianum* and *Triquetrella papillata* (Pottiaceae), *Rosulabryum torquescens* (Bryaceae), *Fissidens leptocladus, Plagiomnium novae-zealandiae* and *Pseudoleskeopsis imbricata*, and thallose liverworts *Plagiochasma rupestre*, *Reboulia hemisphaerica* and *_Lunularia cruciata_. Three hornworts, *Anthoceros punctatus*, *Megaceros gracilis* and *Phaeoceros* cf. *carolinianus* have also been recorded at Colong.

In addition to naturally-occurring limestone areas, many walls, arches and shelter sheds in the Blue Mountains have been built from sandstone and cemented with lime mortar, a perfect substrate for calciphiles. At Blackheath, *Bryoerythrophyllum binnsii* (Pottiaceae) grows on compacted soil near low concrete drains along the path through natural bushland to Govetts Leap. Similarly, *Aloina aloides* var. *ambigua* (Pottiaceae) grows on mortar of an old stone fire place in Megalong Valley, on the southern side of Blackheath. At Mount York Lookout and Mitchells Lookout, west of Mount Victoria, and at the Three Sisters at Katoomba, stone walls in parking areas have an abundance of mosses from the Pottiaceae, including *Barbula crinita*, *Tortula muralis*, *Tortula antarctica*, *Triquetrella papillata* and *Weissia controversa*. *Grimmia pulvinata* is also common and abundant on these walls. Compacted soil close to these structures supports populations of Bryaceae, including *Bryum argenteum*, *Bryum lanatum*, *Gemmabryum dichotomum*, *Gemmabryum pachytheca* and *Rosulabryum torquescens*. *Pseudoleskeopsis imbricata* is occasionally found on mortar or cement.

Urban development in the Blue Mountains– cosmopolitan and introduced species

Urban development in the Blue Mountains rapidly followed the construction of the railway in 1869. The new towns extensively changed the local environment. Non-native species of bryophytes have been introduced and some native species have become particularly abundant.

The small but very conspicuous silver cosmopolitan moss ^{c}*Bryum argenteum* and the thallose liverwort *_Lunularia cruciata_ thrive in areas of high nitrogen, which may originate from garden fertilizer, animal faeces or sewage. ^{c}*Bryum argenteum* also grows in dense cushions in crevices in bitumen or concrete paths. ^{c}*Bryum argenteum* and *Gemmabryum dichotomum* were collected from dumped concrete rubble at Mount Banks.

The mosses ^{c}*Funaria hygrometrica*, *Gemmabryum dichotomum*, *Racopilum cuspidigerum* var. *convolutaceum* and *Rosulabryum billarderi* together with liverworts *Marchantia berteroana* and *_Marchantia polymorpha_ var. *aquatica* are common glasshouse 'weeds' and are often transplanted into gardens with their accompanying plants. Yellowish-orange wefts of the moss *Thuidiopsis sparsa* are common on concrete gutters and drains. *Barbula calycina* and ^{c}*Weissia controversa*, both native species, thrive in compacted roadside soil.

Fig. 9. Alpine bryophytes including *Andreaea subulata*, *Andreaea mutabilis*, *Blindia robusta* and *Polytrichastrum formosum* are part of the vegetation near Darwins Walk, along Jamison Creek from nearby Wentworth Falls Railway Station to the top of Wentworth Falls, shown here.

Table 5. Blue Mountains locations with greatest and least bryophyte species richness

Locations with greatest species richness

	Mosses	Liverworts	Total taxa
Blackheath	131	66	197
Mount Wilson	120	46	166
Wentworth Falls	104	43	147
Lawson	95	49	144

Locations with least species richness

	Mosses	Liverworts	Total taxa
Glenbrook	14	1	15
Kurrajong	28	6	32
Kanangra-Boyd	32	1	33
Springwood	29	9	38

Most of the northern hemisphere trees, such as chestnuts, plane trees, poplars and willows, planted in urban areas of the Blue Mountains, do not shed their bark and their trunks and branches are frequently colonised by many of the epiphytic rainforest bryophytes.

The introduced mosses **Pseudoscleropodium purum*, **Barbula unguiculata*, **Brachythecium albicans* and the introduced thallose liverwort **Lunularia cruciata* occur commonly in parks, home gardens and adjoining bushland. **Barbula unguiculata* grows in abundance on dumped bitumen and soil at Mount Bell on Bells Line of Road; **Pseudoscleropodium purum* and **Brachythecium albicans* grow through lawns in many Blackheath gardens.

Some bryophytes native to the Blue Mountains now grow as 'weeds' elsewhere in the world. These include *Campylopus introflexus*, *Chiloscyphus semiteres*, *Heteroscyphus fissistipus*, *Orthodontium lineare*, *Achrophyllum dentatum* and *Hypopterygium tamarisci*. *Achrophyllum dentatum* and *Hypopterygium tamarisci* are believed to have been imported into Europe on living tree ferns, shipped from Australia for the horticultural industry (Rumsey 2001, Stech & Pfeiffer 2006).

Locations with most taxa: Blackheath, Wentworth Falls, Lawson, Mount Wilson

Blackheath has one of the most extraordinary assemblages of bryophytes of any location in the Blue Mountains. It is located in the higher, western region of the Blue Mountains where rainfall is correspondingly high. The habitats are extremely diverse and include low hills and shallow valleys on the

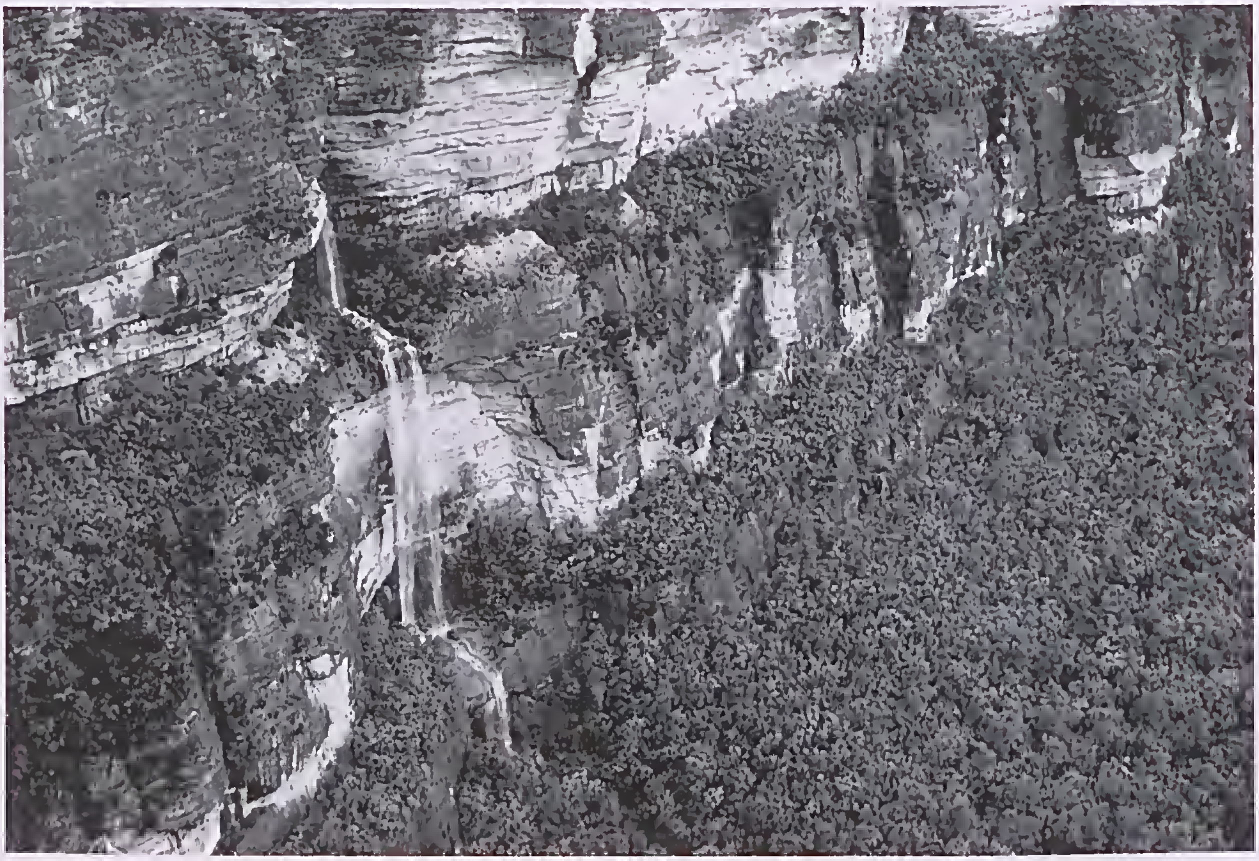

Fig 10. At Bridal Veil Falls, Blackheath, bryophytes, ferns and epacrids are abundant on the cliff face where moisture seeps from horizontal shale bands sandwiched between layers of sandstone.

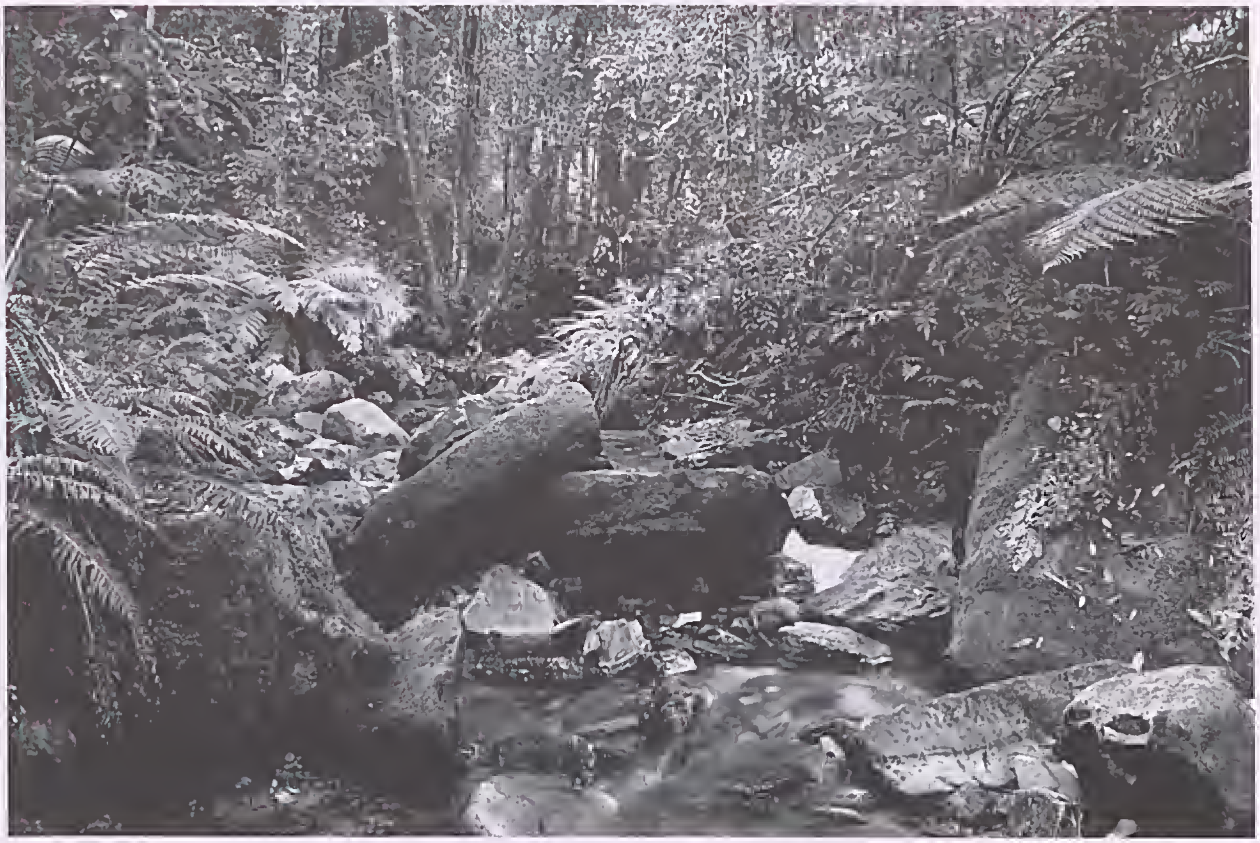

Fig. 11. In closed forest in Megalong Valley, bryophytes are conspicuous on soil, rocks and fallen logs along the creek bank.

plateau tops, steep ridges, sheer cliffs, deep gullies, narrow canyons and massive, wide and deep valleys, including the Grose to the north and the Kanimbla and Jamison Valleys to the south. Access by road and rail is easy and there are many walking tracks that allow access to the valleys (Figure 10).

The bryoflora of the sandstone plateaus includes native species of undisturbed areas, and many species, some native, many introduced, associated with urban and peri-urban sites e.g. epiphytic bryophytes are abundant on many northern hemisphere trees in parks and gardens. There is a great variety of mosses and liverworts in the closed forests of the deep gullies and canyons that dissect the plateau.

Five *Sphagnum* species, *Sphagnum australe*, *Sphagnum cristatum*, *Sphagnum falcatulum*, *Sphagnum novozelandicum* and *Sphagnum perichaetiale*, grow in swamp and seepage areas in hanging valleys on the plateau above the Grose River. The occurrence of five *Sphagnum* species in one area is very rare in New South Wales. Three species of *Andreaea* grow on sandstone boulders deep in gullies and canyons, an unusual location given that the genus normally occurs on granite boulders in alpine areas (Buck, Vitt & Malcolm 2002).

Megalong Valley, south-east of Blackheath, has 25 moss taxa that do not occur at Blackheath, including the very conspicuous mosses *Atrichum androgynum*, *Cyathophorum bulbosum*, *Glyphothecium sciurioides*, *Hypopterygium didictyon*, *Mesochaete undulata*, *Neckera pennata* and *Thamnobryum pumilum* (Figure 13). These very conspicuous species are absent from other gullies and canyons at Blackheath. Megalong Valley is lower in altitude and drier than Blackheath, and is the only location in this study on marine mudstones of the Permian Berry Formation (Figure 11).

Wentworth Falls also has a remarkable bryophyte assemblage. Again, it is in the higher, western section of the Blue Mountains where rainfall is high, access is easy and there is a great range of habitats including many small streams at the top of the plateau and the wet, weeping walls that fringe the sheer cliffs. Alpine taxa found here include *Andreaea mutabilis* and *Andreaea subulata*, *Polytrichastrum alpinum* and *Polytrichastrum formosum*, and *Blindia robusta*. Of 104 moss taxa recorded from Wentworth Falls, 23 are listed as alpine species (Ramsay *et al*. 1986).

Mount Wilson is another high point with high rainfall. It is easily accessible by road and has a great diversity of habitats with heath and woodland on sandstone plateaus and ridges, open and closed forest on basalt tops, closed forest in gullies that dissect sandstone ridges, sheer sandstone cliffs, and deep canyons, including the deep valleys and canyons of the Wollangambe River to the north and Bowens Creek to the south.

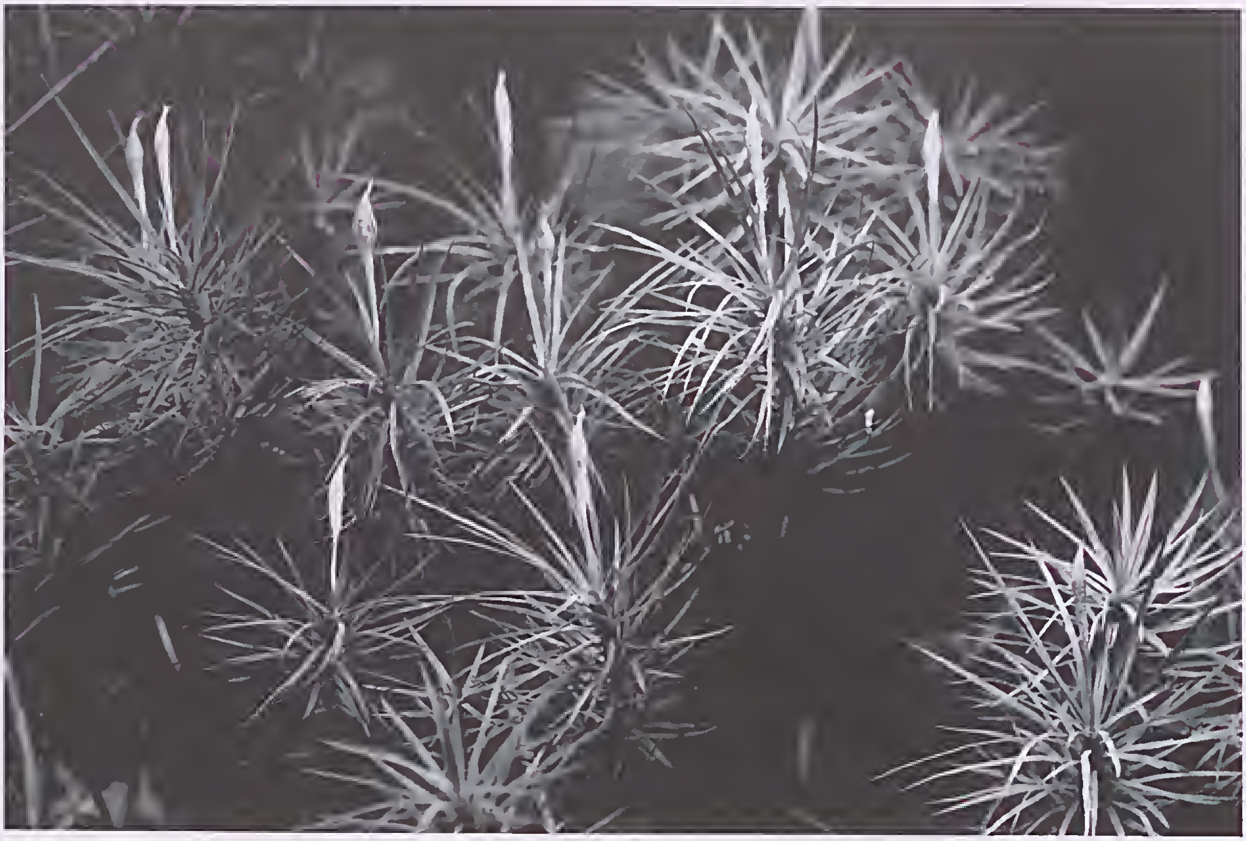

Fig. 12. *Dawsonia superba* var. *pulchra* is common on nutrient rich soils in closed forests. It is a very striking moss with tall, bluish-green stems and red calyptras protecting the young capsules.

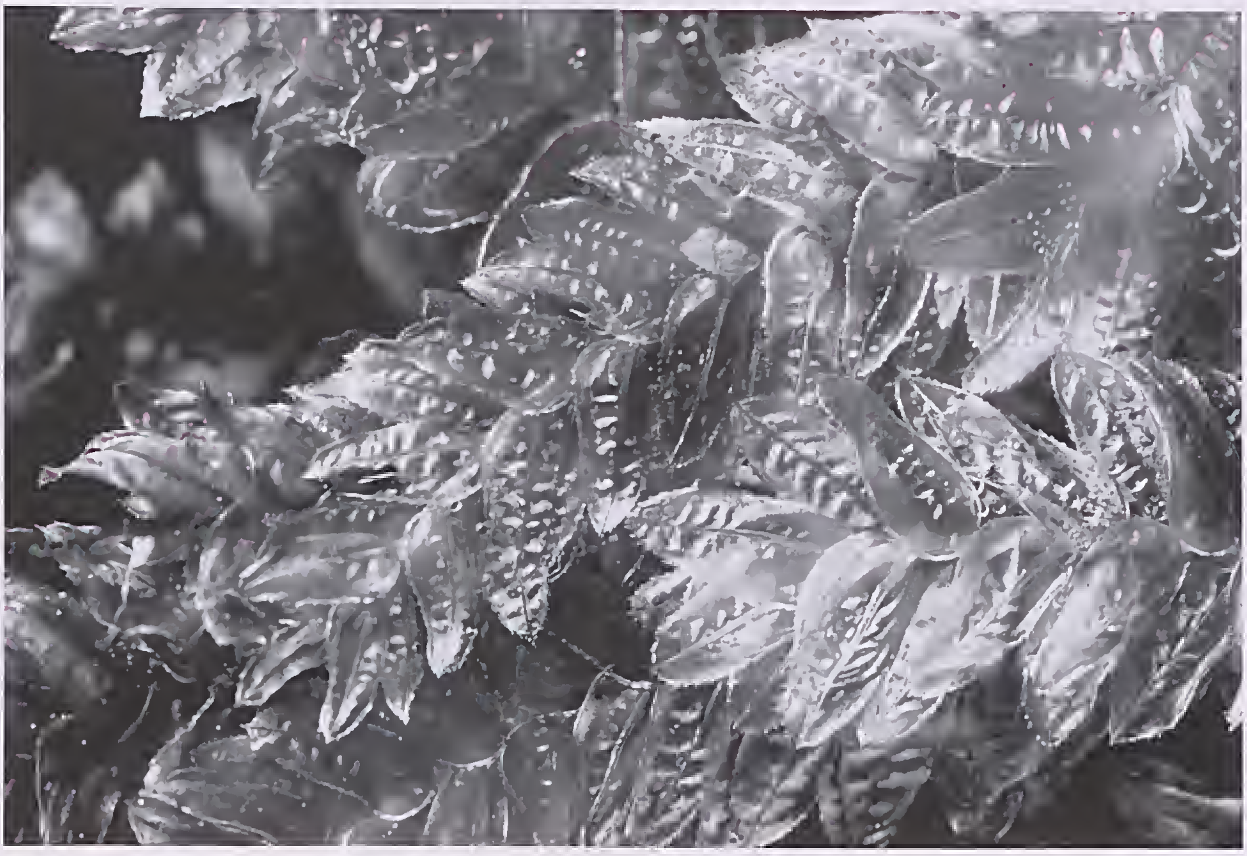

Fig. 13. *Mesochaete undulata* from the closed forest of Megalong Valley is a large, spectacular moss that can be mistaken for a filmy fern.

Bryophytes are abundant in deep shade of closed forests, and include dendroid bryophytes, such as the moss *Hypnodendron vitiense* subsp. *australe* and the liverwort *Hymenophyton flabellatum*, the liverwort-like moss *Achrophyllum dentatum* and thallose liverworts such as *Podomitrium phyllanthus*, *Pallavicinia* spp. and *Symphyogyna* spp. The road from Mount Wilson to Mount Irvine is cut through closed forest providing an 'edge' that is open to the light, thus supporting an assemblage of bryophytes that normally grow on the margins of closed forests such as the epiphytes *Macrocoma tenuis*, *Macromitrium* spp., *Papillaria* spp. and *Frullania* spp. Epiphytes are abundant on ornamental street trees. Bryophyte taxa that are uncommon in the Blue Mountains, including *Asterella drummondii*, *Plagiochasma rupestre*, *Reboulia hemisphaerica* and *Solenostoma inundatum* grow on basalt-derived soils on steep, roadside banks. The thallose liverwort **Lunularia cruciata* occurs here with capsules, rare in the Blue Mountains. Colonising species such as *Dawsonia superba* var. *pulchra*, *Pogonatum neesii* and *Pogonatum subulatum* are common on landslips (Figure 12). Roadsides are commonly covered with *Rosulabryum billarderi* and ^{c}*Polytrichum juniperinum*. Mount Wilson is one of the few locations where hornworts are a conspicuous component of the bryoflora.

Lawson is lower in altitude than Blackheath, Wentworth Falls or Mount Wilson, and has a correspondingly lower rainfall. Although the gullies are not as deep or dramatic as those of the upper Blue Mountains, there is a big range of habitats with creeks, waterfalls and gullies associated with swamps, heath, woodland, open and closed forest, all within close walking distance of the railway station and main highway. Accessibility has probably been a major factor in the size of the collections from this area, with many well-developed walking tracks on both the northern and southern side of the railway station.

Conclusion

This study presents species lists of mosses, liverworts and hornworts recorded from, and provides information on their distribution within the Blue Mountains region of New South Wales. The species lists include collections from both bushland and urban areas. The locations with the most species are in the upper Blue Mountains, where diversity is likely to result from a combination of altitude, rainfall, range of topographic features and accessibility. The species lists include many records from areas, such as Wollemi National Park, Gardens of Stone National Park, Newnes Plateau and Kanangra-Boyd National Park that were not accessible to the early collectors of the late 19th and early 20th centuries. Future collecting in areas that at present are poorly represented, such as Glenbrook, Springwood, Wheeney Creek, Kanangra-Boyd National Park and the canyons fringing Newnes plateau should result in significantly increased species numbers for those areas.

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Vegetation associated with *Wollemia nobilis* (Araucariaceae)

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Abstract: *Wollemia nobilis* Jones et al. (Wollemi Pine) is restricted to four sites growing in warm temperate rainforest typical of the canyons in the Blue Mountains and Wollemi National Parks. 88 vascular plant species were recorded from four sites. The tree canopy at all sites is dominated by *Wollemia nobilis*, *Ceratopetalum apetalum*, *Doryphora sassafras* and *Acmena smithii*. A large number of fern and vine species dominate the forest floor. Site 1 contains more species than the other sites, possibly due to its diversity of topographic features. Similarity analysis indicates that sites 2 and 3 are the most similar and sites 1 and 4 are least similar in floristic composition. 54% of plant species were recorded at one site only. *Ceratopetalum apetalum*, *Blechnum cartilagineum* and *Wollemia nobilis* were found to contribute most to the similarity between sites.

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Introduction

The discovery of the *Wollemia nobilis* Jones et al. (Wollemi Pine) in 1994 in a canyon in the Wollemi National Park west of Sydney, New South Wales (Figure 1) resulted in the description of a new genus in the southern conifer family Araucariaceae. Since then, about 40 publications on many aspects of the conifer have been published (listed on the Botanic Gardens Trust, Sydney web site at www.rbgsyd.nsw.gov.au). This paper documents the associated vascular plant species at the four known sites of *Wollemia nobilis*.

Habitat

Wollemia nobilis is a rare species with 83 plants so far recorded in the wild (J. Benson unpublished data). These are distributed over four sites. However, *Wollemia nobilis* has no detectable genetic variation (Peakall et al. 2003) and it is difficult in the field to determine clonal (ramets) from individuals that originated from seedlings (genets).

All sites of *Wollemia nobilis* occur at the base of Triassic Narrabeen Sandstone cliffs on shallow, sandy loam soils that are acidic with a pH between 3 and 4 (Department of Environment and Conservation NSW 2007). Most of the *Wollemia* trees grow on steep slopes from ranging from 30–80 degrees and on ledges situated 5–20 m above the canyon floor. While some *Wollemia nobilis* trees and seedlings grow on high ledges on these cliffs and mix with typical Blue Mountains dry sclerophyll vegetation, most *Wollemia* trees grow in warm temperate rainforest that dominates the lower slopes and lower ledges. This type of rainforest is common in canyons and gullies in the Blue Mountains and Wollemi National Parks (Floyd 1990). The canyons retain a relatively high humidity compared to the slopes above and the evaporation rates are limited by shade and protection from desiccating winds. Most of the *Wollemia* trees grow within 20 m of streams and their roots often extend down slope into the canyon floor where water is available all year round. This attribute may explain how *Wollemia nobilis* has survived drought.

The canyons are protected from most wildfires but there is evidence that many if not most *Wollemia* trees have been burnt at all sites. Too intense or too frequent fire may threaten the survival of *Wollemia nobilis* by killing trees and seedlings. However, the ability of the species to grow suckers from basal buds allows it to re-sprout after disturbance including rock falls and fire. Periodic disturbance, perhaps on a small scale, is probably required to produce canopy gaps that allow more light to reach the forest floor thereby providing the opportunity for seedlings to mature and grow into adult plants (T. Auld & J. Benson pers. comm.).

Methods

Vascular plant species were recorded from the four known groves of *Wollemia nobilis* in 2001 and 2002. Plant species were recorded from the area within the boundary of the canopy dominance of *Wollemia nobilis*. Cover scores were assigned to each species present based on a modified Braun-Blanque scale (Poore 1955). Floristic and vegetation structural data was entered into the NSW Department of Environment and Conservation MS Access Floristic Site Survey YETI Database. Physical attributes of the sites were also recorded but the latitude and longitude of the sites were not recorded or data-based in order to maintain the confidentiality of the locations.

The sites were not uniform in size so the interpretation of the analyses of the data needs to take this into account. Site 1 covers 100 m x 100 m; site 2, 150 x 30 m; site 3, 20 x 20 m; and site 4, 200 m x 30 m. These areas reflect the total area of canopy cover dominance of the *Wollemia nobilis* in the wild, i.e. about 2.2 hectares.

The site floristic data were analysed using Primer V4.0 and transferred to MS Excel for graphing and summary presentation. Non-metric multi-dimensional scaling (MDS) ordination using Bray Curtis similarities from normalised (double root-transformed) species cover rating was applied to the species data (Sokal & Rohlf 1995). Plant species presence was determined for each of the sites and was expressed in a plant species presence biplot in a MDS ordination on Bray-Curtis similarities. Plant species coverage of each study site was also recorded and given a score of 1–6, in which 1=0.01–1%, 2=1–5%, 3=5–25%, 4 =25–50% and 5=50–75% and 6=>75%. To produce similarities based on % coverage class, calculations were repeated for each species using the maximum and minimum possible percentage within each class and the resultant points on the biplot joined to produce a closed curve delimiting the possible range of similarities. This gave a range of possible plant species coverages for each site. Results were depicted on the same biplot, expressed as an MDS ordination on Bray-Curtis similarities, although analysed separately to the presence/absence data.

Results

Description

88 vascular plant species were recorded in the 2.2 hectares of warm temperate rainforest that contain the four sites of *Wollemia nobilis* (Table 1). Ferns, vines, trees and shrubs were the main growth forms with a low number of grasses, forbs and sedges (Table 2).

All sites contain a closed canopy vegetation structure with a sparse layer of shrubs or young trees and a dense layer of ferns. Vines are a common feature at all sites. A tree stratum averaging 20–30 m high is dominated by the rainforest trees *Wollemia nobilis* (Wollemi Pine), *Ceratopetalum apetalum* (Coachwood), *Doryphora sassafras* (Sassafras) and *Acmena smithii* (Lilly Pilly). *Backhousia myrtifolia* (Grey Myrtle) was recorded only at site 1. Some *Wollemia nobilis* stems are over 30 m high and emerge above the rainforest canopy.

Eucalyptus occur in low numbers including *Eucalyptus piperita* (Sydney Peppermint) at sites 1 and 3 and *Eucalyptus punctata* (Grey Gum) at site 2. *Angophora costata* occurs just outside the site 1 *Wollemia* stand. Small rainforest trees or shrubs include *Ficus coronata* (Sandpaper Fig), *Elaeocarpus reticulatus* (Blueberry Ash), *Notelaea longifolia* (Mock Olive) and *Eupomatia laurina* (Bolwarra). *Dicksonia antarctica* (Soft Treefern) is common at all sites while *Cyathea australis* (Rough Treefern) was recorded only at site 4. On the upper slope margins of *Wollemia* extent, dry sclerophyll shrubs including the small trees/shrubs *Allocasuarina torulosa*, *Leptospermum trinervium*, *Nematolepis squamea* subsp. *squamea* and *Persoonia linearis* mix with rainforest species. A few species of heath-shrub in the family Epacridaceae grow on ledges or in cracks in the sandstone cliffs – these include *Dracophyllum secundum* and *Rupicola ciliata*.

A feature of the rainforest is the abundance of vines. Some vines such as *Pandorea pandorana*, *Morinda jasminoides* and *Parsonsia purpurescens* climb to the canopy of the forest. Others, such as *Smilax glyciphylla* and *Rubus* spp. are bushy scramblers on the forest floor.

21 species of ferns were recorded. *Sticherus flabellatus* var. *flabellatus* dominates the ground cover at site 1 and is a co-dominant at the other sites. *Blechnum cartilagineum* dominates the forest floor at all sites but especially at site 3 and on the upper slopes of site 4 that are drier and more exposed than most of the habitat at site 1 and site 2. *Lastreopsis acuminata* is common at all sites but absent from the driest site (site 3). *Todea barbara* is common on the banks of the streams. *Blechnum patersonii*, *Blechnum wattsii* and *Leptopteris fraseri* occur on moister, lower slopes, in sandstone overhangs or along streams on the canyon floors where light levels are low. Other fern species include *Asplenium flabellifolium*, *Pellaea falcata* var. *nana* and *Calochlaena dubia*.

Few grasses, sedges, rushes or forbs grow under the dense fern ground cover. *Lomandra filiformis* subsp. *filiformis* is commonly found growing on rock ledges. Lithophytes include the orchid species *Liparis reflexa* and *Dendrobium teretifolium* that grow on cliffs. Epiphytes include the fern *Tmesipteris parva* growing on the trunks of treeferns, the mistletoe *Muellerina celastroides* growing in the canopy of *Ceratopetalum apetalum* trees, and *Sarchochilus falcatus* (Orange Blossum Orchid) growing on the upper branches of rainforest trees. No vascular epiphytes have been recorded growing on *Wollemia nobilis*.

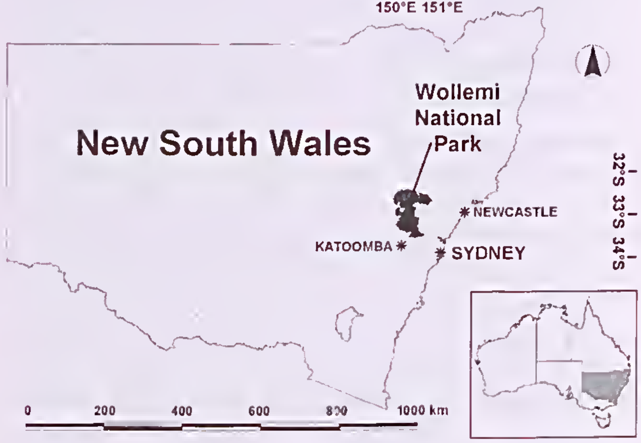

Fig. 1. Location of Wollemi National Park in New South Wales, Australia

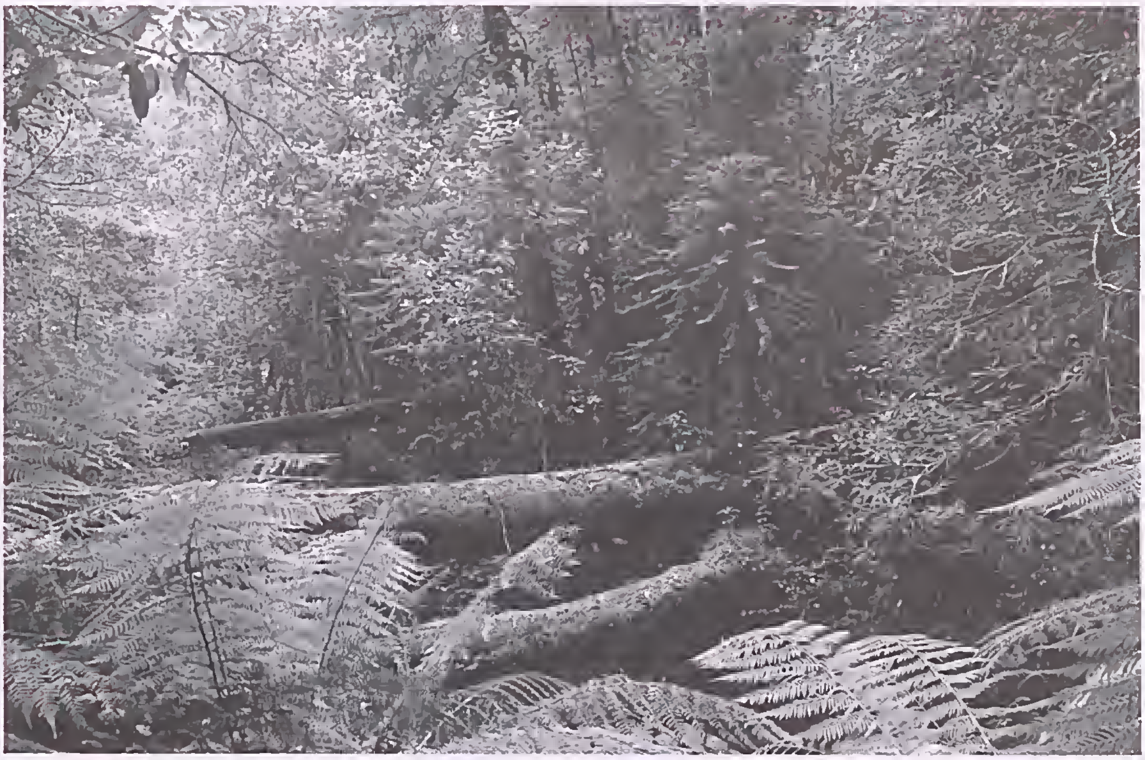

Fig. 2. The habitat of Wollemia nobilis at site 1 showing warm temperate rainforest dominated by Ceratopetalum apetalum (Coachwood) and Doryphora sassafras (Sassafras) with a dense ground cover of ferns. Photograph Jaime Plaza.

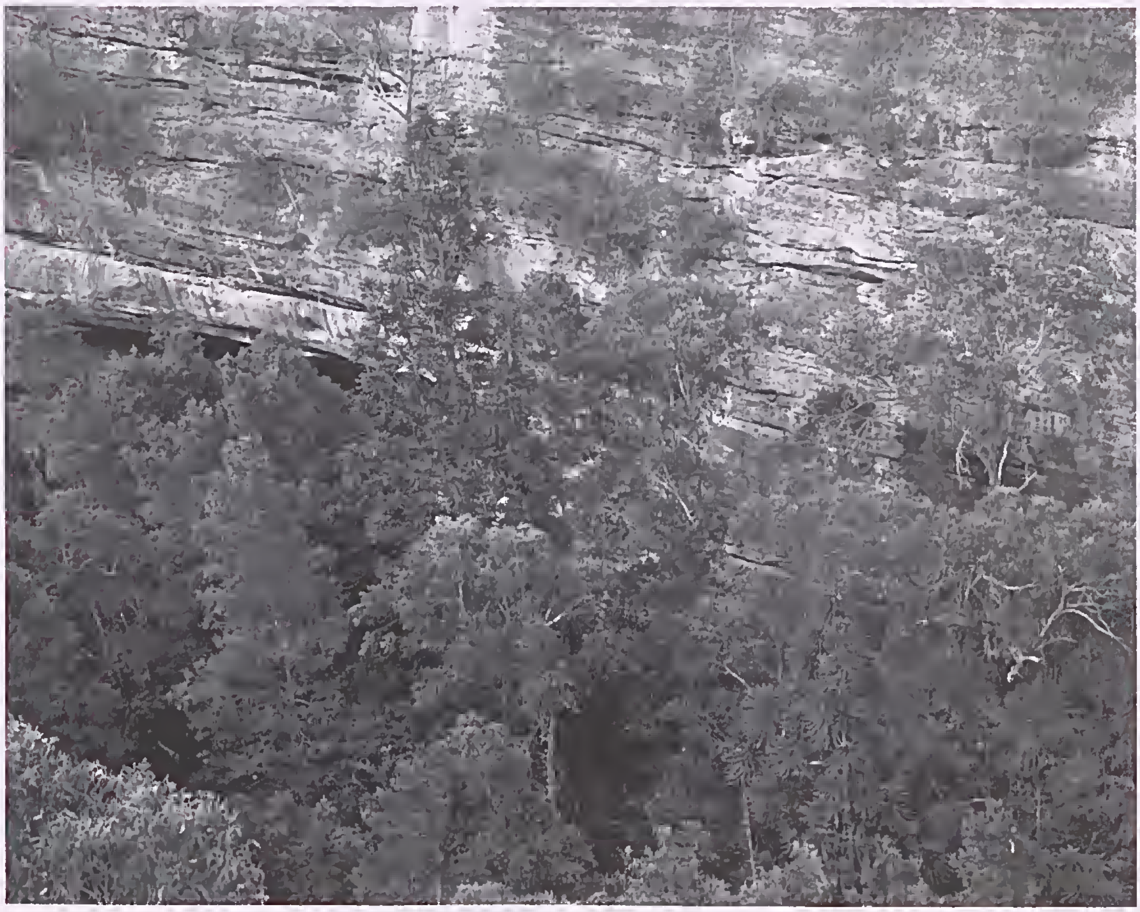

Fig. 3. Oblique aerial photograph of the site 1 of Wollemia nobilis showing the canyon environment, sandstone cliffs, rainforest habitat with some Eucalyptus present. Photograph John Benson.

Table 1. Cover ratings of vascular plant species recorded at *Wollemia nobilis* sites.

Growth form definitions are modified from Walker & Hopkins (1990). Cover ratings per site 1 = <1%, 2 = 1–5%, 3 = 5–25%, 4 = 25–50%, 5 = 50–75%, 6 = >75%

Species (family)	Growth form	Site 1	Site 2	Site 3	Site 4
Acacia longifolia (Fabaceae-Mimosoideae)	Shrub	-	1	-	-
Acmena smithii (Myrtaceae)	Tree	4	2	2	3
Adiantum formosum (Adiantaceae)	Fern	1	-	-	-
Adiantum hispidulum (Adiantaceae	Fern	-	1	-	-
Allocasuarina torulosa (Casuarinaceae)	Tree	1	1	1	-
Amperea xiphoclada (Euphorbiaceae)	Shrub	1	-	-	-
Aphanopetalum resinosum (Cunoniaceae)	Vine	1	-	-	-
Asplenium flabellatum Adiantaceae	Fern	1	-	-	-
Asplenium flabellifolium (Aspleniaceae)	Fern	1	1	1	1
Backhousia myrtifolia (Myrtaceae)	Tree	2	-	-	-
Blechnum cartilagineum (Blechnaceae)	Fern	3	3	4	4
Blechnum nudum (Blechnaceae)	Fern	2	-	-	-
Blechnum patersonii (Blechnaceae)	Fern	1	3	1	1
Blechnum penna-marina subsp. *alpina* (Blechnaceae)	Fern	-	-	1	-
Blechnum wattsii (Blechnaceae)	Fern	1	1	1	-
Callicoma serratifolia (Cunoniaceae)	Tree	1	-	-	-
Calochlaena dubia (Dicksoniaceae)	Fern	-	-	1	3
Cephalaralia cephalobotrys (Araliaceae)	Vine	1	-	-	-
Ceratopetalum apetalum (Cunoniaceae)	Tree	5	4	5	4
Cissus hypoglauca (Vitaceae)	Vine	-	1	-	-
Clematis glycinoides (Ranunculaceae)	Forb	1	-	1	-
Cyathea australis (Cyatheaceae)	Tree-fern	-	-	-	1
Dendrobium teretifolium (Orchidaceae)	Lithophyte	1	1	-	-
Dianella caerulea (Phormiaceae)	Forb	-	1	-	1
Dicksonia antarctica (Dicksoniaceae)	Tree-fern	3	2	3	2
Dillwynia elegans (Fabaceae-Faboideae)	Shrub	1	-	-	-
Diplazium australe (Athyriaceae	Fern	1	-	-	-
Doodia aspera (Blechnaceae)	Fern	3	-	-	-
Doryphora sassafras (Monimiaceae)	Tree	4	3	1	2
Dracophyllum secundum (Epacridaceae)	Heath-Shrub	2	2	1	1
Elaeocarpus reticulates (Elaeocarpaceae)	Tree	1	1	1	1
Entolasia stricta (Poaceae)	Tussock grass	-	-	1	-
Eucalyptus piperita (Myrtaceae)	Tree	1	-	1	-
Eucalyptus punctata (Myrtaceae)	Tree	-	1	-	-
Eupomatia laurina (Eupomatiaceae)	Shrub	1	1	-	1
Ficus coronata (Moraceae)	Tree	1	-	-	1
Ficus rubiginosa (Moraceae)	Tree	1	-	-	-
Fieldia australis (Gesneriaceae)	Vine	1	-	-	1
Gratiola nana (Scrophulariaceae)	Forb	1	-	-	-
Hedycarya angustifolia (Monimiaceae)	Tree	1	-	-	-
Hydrocotyle laxiflora (Apiaceae)	Forb	1	-	-	-
Lastreopsis acuminata (Dryopteridaceae)	Fern	2	2	-	3
Lastreopsis microsora subsp. *microsora* (Dryopteridaceae)	Fern	1	-	-	-
Lepidosperma laterale (Cyperaceae)	Sedge	1	1	1	-
Leptopteris fraseri (Osmundaceae)	Fern	1	1	1	-
Leptospermum trinervium (Myrtaceae)	Shrub	1	1	1	-
Leucopogon lanceolatus (Epacridaceae)	Heath-Shrub	-	1	-	-
Libertia paniculata (Iridaceae)	Forb	1	-	-	-
Lindsaea microphylla (Lindsaeaceae)	Fern	1	-	-	-
Liparis reflexa (Orchidaceae)	Lithophyte	-	-	-	1
Logania albiflora(Loganiaceae)	Shrub	-	-	1	-
Lomandra filiformis subsp. *filiformis* (Lomandraceae)	Rush	1	2	2	-
Lomatia silaifolia (Proteaceae)	Shrub	1	-	-	-
Marsdenia rostrata (Asclepiadaceae)	Vine	1	-	-	-
Microsorum scandens (Polypodiaceae)	Vine	1	1	-	1
Morinda jasminoides (Rubiaceae)	Vine	1	1	1	1
Muellerina celastroides (Loranthaceae)	Epiphyte	1	-	-	-
Nematolepis squamea subsp. *squamea* Rutaceae	Shrub	1	1	1	-
Notelaea longifolia (Oleaceae	Shrub	1	1	-	-
Omalanthus populifolius (Eupomatiaceae	Shrub	1	-	-	-
Oplismenus aemulus (Poaceae)	Tussock grass	1	-	-	-
Pandorea pandorana (Bignoniaceae)	Vine	1	1	1	1
Parsonsia leichhardtii (Apocynaceae)	Vine	-	-	-	1
Parsonsia purpurascens (Apocynaceae)	Vine	1	1	1	1

Pellaea falcata var. *falcate* (Adiantaceae)	Fern	-	-	-	1
Pellaea falcata var. *nana* (Adiantaceae)	Fern	3	2	1	-
Persoonia linearis (Proteaceae)	Shrub	1	1	-	1
Pittosporum undulatum (Pittosporaceae)	Tree	1	-	-	-
Rapanea variabilis (Myrsinaceae)	Shrub	-	1	-	-
Rubus hillii (Rosaceae)	Vine	1	1	-	1
Rubus moluccanus var. *trilobus* (Rosaceae)	Vine	1	1	-	1
Rubus parvifolius (Rosaceae)	Vine	-	-	-	1
Rupicola ciliata (Epacridaceae)	Heath-Shrub	-	1	-	-
Sarchochilus falcatus (Orchidaceae)	Epiphyte	1	-	-	-
Schoenus apogon (Cyperaceae)	Sedge	1	-	-	-
Schoenus melanostachys (Cyperaceae)	Sedge	1	1	1	-
Scutellaria humilis (Lamiaceae)	Forb	1	-	-	-
Smilax glyciphylla (Smilacaceae)	Vine	1	1	1	1
Stellaria flaccida (Caryophyllaceae)	Forb	1	-	-	-
Sticherus flabellatus var. *flabellatus* (Gleicheniaceae)	Fern	4	2	2	2
Stylidium graminifolium (Stylidiaceae)	Forb	-	1	-	-
Stypandra glauca (Phormiaceae)	Forb	-	1	-	-
Styphelia tubiflora (Epacridaceae)	Heath-Shrub	-	-	1	-
Tmesipteris parva (Psilotaceae)	Epiphyte	1	-	-	-
Todea barbara (Osmundaceae)	Fern	2	2	-	2
Trophis scandens (Moraceae)	Vine	1	-	-	-
Wollemia nobilis (Araucariaceae)	Tree	4	3	3	4
Xanthorrhoea glauca (Xanthorrhoeaceae)	Grass-tree	1	-	-	-

Table 2. Growth forms, based on Walker & Hopkins (1990), of the vascular plant species associated with the *Wollemia nobilis*

Growth Form	Number of species
Tree	14
Shrub	12
Heath Shrub	4
Tree Fern	2
Grass Tree	1
Vine	15
Fern	20
Forb	9
Sedge	3
Rush	1
Tussock Grass	2
Epiphyte	3
Lithophyte	2
Total	88

Table 3. Plant species occurrences at and between sites

	Site 1		Site 2		Site 3		Site 4		All Sites	
No. species	68		43		31		31		88	
No. species at 1 site	31	46%	8	19%	4	13%	5	16%	49	56%
No. species at 2 sites	6	9%	3	7%	4	13%	4	13%	8	9%
No. species at 3 sites	15	22%	16	37%	9	29%	7	23%	16	18%
No. species at 4 sites	15	22%	15	35%	15	48%	15	48%	15	17%

Table 4. Similarity between site plant species coverages (for species >1.0% similar)

	Average % Coverage	% Similar	Cumulative % Similar
Ceratopetalum apetalum	50	6.32	6.32
Blechnum cartilagineum	26.25	5.05	11.36
Wollemia nobilis	26.25	4.86	16.22
Acmena smithii	14.63	3.42	19.63
Dicksonia antarctica	9	3.31	22.94
Sticherus flabellatus var. *flabellatus*	11.63	3.05	26.00
Doryphora sassafras	14	2.66	28.66
Dracophyllum secundum	1.75	1.73	30.39
Lastreopsis acuminata	5.25	1.62	32.01
Todea barbara	2.25	1.44	33.45
Elaeocarpus reticulatus	0.5	1.22	34.68
Asplenium flabellifolium	0.5	1.22	35.90
Parsonsia purpurascens	0.5	1.22	37.12
Pandorea pandorana	0.5	1.22	38.35
Morinda jasminoides	0.5	1.22	39.57
Smilax glyciphylla	0.5	1.22	40.79
Lomandra filiformis subsp. *filiformis*	1.63	1.16	41.95
Pellaea falcata var. nana	4.63	1.11	43.06
Blechnum patersonii	4	1.07	44.13

Table 5. Proportion of species common to combinations of sites

Site1 & Site 4	30%
Site 3 & Site 4	32%
Site 3 & Site 1	35%
Site 2 & Site 4	42%
Site 2 & Site 1	43%
Site 2 & Site 3	50%

Table 6. Plant species coverage differences between sites for species with >1.1% dissimilarity scores

Sites 2 and 3	**42.79% Dissimilar**	
	Dissimilarity %	**Cumulative %**
Lastreopsis acuminata	1.75	1.75
Todea barbara	1.75	3.50
Blechnum patersonii	1.70	5.20
Doryphora sassafras	1.69	6.89
Sites 2 and 4	**44.12% Dissimilar**	
	Dissimilarity %	**Cumulative %**
Calochlaena dubia	2.58	2.58
Lomandra filiformis subsp. *filiformis*	1.73	4.31
Pellaea falcata var. *nana*	1.71	6.02
Blechnum patersonii	1.67	7.69
Sites 1 and 2	**46.48% Dissimilar**	
	Dissimilarity %	**Cumulative %**
Blechnum patersonii	1.85	1.85
Doodia aspera	1.81	3.66
Blechnum nudum	1.21	4.87
Backhousia myrtifolia	1.21	6.08
Sticherus flabellatus var. *flabellatus*	1.17	7.26
Acmena smithii	1.17	8.43
Sites 3 and 4	**50.18% Dissimilar**	
	Dissimilarity %	**Cumulative %**
Lastreopsis acuminata	3.02	3.02
Lomandra filiformis subsp. *filiformis*	2.01	5.04
Todea barbara	2.00	7.04
Calochlaena dubia	1.93	8.96
Sites 1 and 4	**52.87% Dissimilar**	
	Dissimilarity %	Cumulative %
Calochlaena dubia	2.03	2.03
Pellaea falcata var. *nana*	1.99	4.02
Doodia aspera	1.99	6.01
Blechnum nudum	1.33	7.34
Backhousia myrtifolia	1.33	8.68
Doryphora sassafras	1.29	9.97
Sticherus flabellatus var. *flabellatus*	1.28	11.26
Sites 1 and 3	**53.63% Dissimilar**	
	Dissimilarity %	**Cumulative %**
Doodia aspera	2.02	2.02
Doryphora sassafras	1.96	3.98
Lastreopsis acuminata	1.38	5.36
Todea barbara	1.38	6.75
Blechnum nudum	1.35	8.10
Backhousia myrtifolia	1.35	9.45
Pellaea falcata var nana	1.31	10.76
Sticherus flabellatus var. *flabellatus*	1.31	12.07
Acmena smithii	1.31	13.38

Floristic variation between sites

While there is high congruence in canopy species composition across the four sites, analyses of all plant species records reveals variation in floristic composition. Site 1 contained more species than the other sites including more than twice that of the similar sized site 4 (Table 3). Compared to the other sites, site 1 also contained over three-fold the number and proportion of plant species that were only found at one site. 15 (17%) plant species were recorded in one site, 16 (18%) were recorded in two sites, 8 (9%) were recorded in three sites, and 49 (56%) were recorded in all sites (Table 3). However, only three of the 31 species recorded only at site 1 had greater than 1% cover, and none of the species unique to sites 2, 3 or 4 had greater than 1% cover.

When considering all plant species presence / absence, the four sites are 57% similar. Site 2 was most similar to all other sites in a plant species presence biplot, expressed as an MDS ordination on Bray-Curtis similarities (Figure 4), but sites 1, 3 and 4 were almost equidistant from each other. Based on Bray-Curtis similarities of species present (Figure 4), and on the percentage of species common to any two sites (Table 5), sites 2 and 3 are the most similar, then sites 2 and 1 or sites 2 and 4, then sites 1 and 3, 3 and 4, with sites 1 and 4 being least similar. The plant species that were most responsible for the similarity between the sites were *Ceratopetalum apetalum*, *Blechnum cartilagineum* and *Wollemia nobilis* (Table 4). Almost half of the difference in site species coverage for species >1.1% dissimilarity was due to absence of species from a site (Table 6).

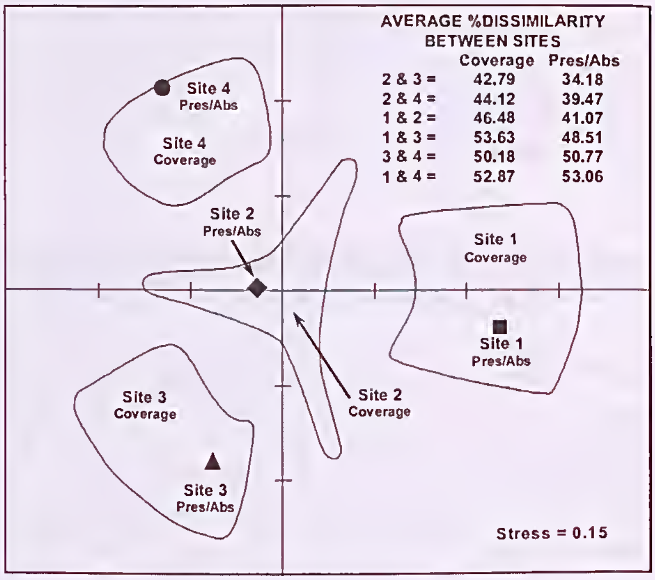

Fig. 4. Non-metric multi-dimensional scaling (MDS) ordination of Bray Curtis similarities from double root-transformed species presence and percentage cover ratings for *Wollemia nobilis* sites 1 to 4. Each site's plant species presence is represented on the plot as a single point. Plant species percent coverage of each study site is represented by a closed curve delimiting the possible range of similarities.

Discussion

Most of the vascular plant species associated with *Wollemia nobilis* are common species of the canyons and gorges of the Blue Mountains region west of Sydney (Floyd 1990, Bell 1998). The vegetation at all sites of *Wollemia nobilis* is similar to the description of warm temperate rainforest sub-alliances 36 and 37 in Floyd (1990). This type of rainforest is widespread in the Blue Mountains and Wollemi National Parks. Postulations about why the *Wollemia nobilis* itself is so restricted are to be discussed elsewhere (J. Benson and T. Auld unpublished data).

Dominance of fern species at the different sites may reflect differences in humidity and light. For example, most of site 4 is dominated by *Blechnum cartilagineum*, that can tolerate relatively dry conditions and high light situations while *Sticherus flabellatus* var. *flabellatus* dominates the ground cover at site 1. The latter does not tolerate its root system drying out (Jones & Clemesha 1981) and tends to grow in lower light situations than *Blechnum cartilagineum*. This indicates the ground cover at site 1 is probably on average wetter than site 4. The higher floristic diversity of site 1 can probably be explained by its larger area and diverse micro-habitats compared to the other sites. Site 1 includes a large canyon, a narrow side canyon, a large watercourse and a larger range of aspects than the other sites.

Fire history can alter the boundaries and floristic composition of rainforest. The presence of *Eucalyptus piperita* at sites 1 and 3 and *Eucalyptus punctata* at site 2 within the *Wollemia nobilis* groves, indicates there were sufficient gap openings in the past for *Eucalyptus* seed to germinate and grow into adult trees. These gaps were possibly caused by disturbance events such as rock falls, windfalls or bushfire. It is likely that burning logs and branches have fallen into *Wollemia nobilis* groves from slopes above the clifflines at the sites. Some fires at the sites may have been patchy, others may have burnt the whole site. The smallest site, site 3, that contains six, small *Wollemia nobilis* trees growing next to sclerophyll vegetation composed of *Allocasuarina torulosa*, *Leptospermum trinervium* and *Eucalyptus piperita*, may be susceptible to more frequent fire than the other three sites.

The long-term survival of *Wollemia nobilis* will depend on a number of factors including maintaining its habitat and excluding or controlling pathogens. If associated angiosperm tree species such as *Ceratopetalum apetalum* and *Doryphora sassafras* are demonstrated to be out-competing *Wollemia*, in the absence of intermittent disturbance, this raises the issue of whether human-induced disturbance would be an appropriate management response to maintain the *Wollemia* populations. It is suggested that further monitoring and research is required before such action is taken.

Recent tests have revealed that the root pathogen *Phytophthora cinnamomi* has infected some trees at site 1 (Brett Summerell pers. comm.). In vitro experiments have revealed that *Wollemia* is susceptible to *Phytophthora cinnamomi* (Bullock et al. 2000) particularly when the trees are stressed. While it is not known how the pathogen arrived, site 1 is known to have been visited illegally by a number of people over the last 10 years. Illegal visitation could also result in the trampling of *Wollemia* seedlings and erosion of the shallow soil on the steep slopes where the tree grows. For these reasons the location and juxtaposition of the groves of *Wollemia nobilis* have not been released to the general public.

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Mr Chris Pavich of the Parks and Wildlife Division of NSW Department of Environment and Conservation assisted with the field work. The Wollemi Pine Recovery Team provided comments on the manuscript.

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Observations on the ecology and conservation status of *Haloragis exalata* subsp. *exalata* (Haloragaceae) in southern New South Wales

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Abstract: Haloragis exalata F. Muell. subspecies *exalata* (family Haloragaceae), a perennial forb, is currently listed as Vulnerable, under both national and New South Wales threatened species conservation legislation. Very few herbarium records existed until recently.

Recent discoveries of *Haloragis exalata* subsp. *exalata* in new sites on the NSW South Coast and Southern Tablelands prompted us to carry out surveys for the two varieties of the taxon, var. *exalata* and var. *laevis*. Our surveys in 2004–2007 aimed to relocate historical collection sites and target areas of potentially suitable habitat in these areas.

Our work has substantially increased the number of known localities for *Haloragis exalata* subsp. *exalata* var. *exalata*. It can be locally abundant. Ecologically it appears to function as a gap species whose populations are almost invariably found at sites where disturbance through temporary inundation, physical disturbance, or fire, has exposed bare earth with higher levels of light at ground level than would be present when the local vegetation community is intact. There are morphological differences between populations in disjunct areas. *Haloragis exalata* subsp. *exalata* var. *laevis* is much more restricted.

As a result, the conservation status of *Haloragis exalata* subsp. *exalata* may need revision, considering that a) var. *exalata* is more widespread than previously known, but that b) there is only one known extant population of var. *laevis*, and that c) the population from Geehi area may be a distinct taxon.

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Introduction

Haloragis exalata (family Haloragaceae) is described as a shrub to 1.5 m high (Wilson 2002, Jeanes 1996) with 4-angled, red stems and opposite and decussate, toothed, lanceolate leaves. Inconspicuous flowers to 3 mm long are borne in extended leafy terminal or upper axillary inflorescences. *Haloragis exalata* is divided into two subspecies, *exalata* and *velutina* (subspecies *velutina* is restricted to northern NSW and Queensland, and not discussed further here). *Haloragis exalata* subsp. *exalata* is itself subdivided into two varieties, var. *exalata* (with scabrous stems and leaves) and var. *laevis* (distinguished by its glabrous stems and leaves).

Haloragis exalata subsp. *exalata* var. *exalata* has been historically recorded from a single location in the Hunter Valley (Moonan Brook near Scone in 1886) (Orchard 1990), the Nepean River near Sydney, Clifton near Wollongong and the South Coast (Tilba Tilba in 1880 and Mt Dromedary in 1889). Its habitat has been described as "damp riparian habitat" (Jeanes 1996) and "damp places near watercourses" (Wilson 2002). The majority of early herbarium specimens come from two areas in south-western Victoria: the Curdies River near Port Campbell (1894, 1900, 1966), and the lower Glenelg River (1891, 1945, 1946, 1950, 1954, 1969 and 1981). *Haloragis exalata* subsp. *exalata* var. *laevis* is apparently restricted to the Central Coast botanical division of NSW with historical records from the Nepean River and Parramatta (Orchard 1990).

Because of the very small number of modern records (prior to 2001), *Haloragis exalata* subsp. *exalata* is listed as Vulnerable under the NSW *Threatened Species Conservation Act (1995)* and nationally under the *Environment Protection and Biodiversity Conservation Act (1999)*. It is not listed under the Victorian *Flora and Fauna Guarantee Act (1988)*, although it is listed as vulnerable in Victoria on the *Advisory List of Rare or Threatened Plants in Victoria – 2005* (Department of Sustainability & Environment 2005).

In 2001–02 one of us (JM) discovered new populations of *Haloragis exalata* subsp. *exalata* var. *exalata* on the South Coast and in the Geehi Dam area of Kosciuszko National Park. Because of the conservation significance of *Haloragis exalata* subsp. *exalata*, we then followed up recent field records in the NSW South Coast, Illawarra and Kosciuszko regions with targeted field surveys to assess its current distribution, ecology and conservation status.

Methods

Specimens of the various subspecies and varieties of *Haloragis exalata,* and the related and very similar *Haloragis serra,* held at major herbaria (NSW, MEL, CANB) were examined. *Haloragis exalata* subsp. *velutina* is readily distinguishable from the remaining three taxa by the dense covering of short, uniform hairs on both stems and leaves. The other three taxa (*Haloragis serra* and *Haloragis exalata* subsp. *exalata* var. *exalata,* and var. *laevis*) are less easy to separate in the absence of fertile material (*H. serra* has 2-locular fruits and *H. exalata* 4-locular fruits) (Figures. 2, 3, 5).

Between 2004 and 2007 we carried out a series of targeted surveys on the NSW South Coast, revisiting the sites of past records to survey the areas more thoroughly, and searching numerous additional coastal lakes and estuaries which we considered might also harbour populations. Our surveys generally concentrated on the type of areas we had already found to be most likely to carry *Haloragis exalata* populations, low-lying shorelines and the mouths of small gullies. A large proportion of the shoreline of many of these southern lakes is steep, rocky and clothed with dry *Eucalyptus* forest and unlikely to be suitable for *Haloragis exalata.* Where the number of plants present was small (<50) an attempt was made to count individual plants, otherwise numbers were estimated, by counting a small area and extrapolating to the larger area. However, numbers are very difficult to estimate accurately due to the tangle of stems which forms when more than a few plants are growing together.

During the surveys we made observations on plant size and abundance, habitat and recruitment strategies and the impact of fire and disturbance regimes. Not all new populations were recorded as a result of targeted surveys: some additional serendipitous discoveries were made during other survey work. The surveys have been conducted over several years; some sites have been visited several times to observe responses to disturbance, principally flood events. For example a flood event affecting the Wallaga and Cuttagee Lake catchments in July 2005 opened both lakes to the sea, after a period of about 48 hours of very high water level. This provided an opportunity to observe the effect of a brief inundation on *Haloragis exalata* subsp. *exalata,* many plants of which were totally or partially submerged during this period. We carried out limited experimentation on seed germination and buoyancy in relation to flood conditions using samples of 100 freshly collected fruits.

We also looked at morphological variation in plants currently subscribed under *Haloragis exalata* subsp. *exalata* var. *exalata,* particularly between specimens collected from the south coast populations and those near Geehi in Kosciuszko National Park in the Southern Tablelands.

Haloragis serra (which is not listed as threatened) has been confused with *Haloragis exalata* subsp. *exalata* in both herbarium specimens and DECC Wildlife Atlas records. We therefore examined herbarium specimens and searched for it in Bungonia Gorge where it had previously been recorded, to clarify differences in appearance and habitat.

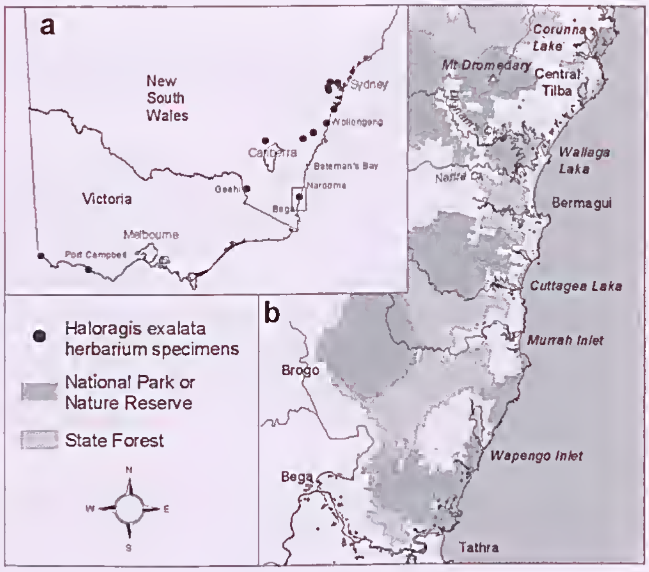

Fig. 1. a) Recorded collection sites of *Haloragis exalata* subsp. *exalata* and b) recently surveyed sites on the NSW far south coast.

Table 1 Current north to south geographical distribution of *Haloragis exalata* subsp. *exalata* var. *exalata* in southern New South Wales with field observations on population numbers (2004–2007), and locations of some related *Haloragis* taxa that have caused confusion.

a) Current distribution of *Haloragis exalata* subsp. *exalata* var. *exalata*

Otford to Coledale

In February 2007 we found only 6 plants, on a small, weedy area of road verge adjacent to a regrowth rainforest patch at Coalcliff, after searching between Otford and Coledale, concentrating on riparian sites and areas of waste ground, within this now predominantly suburban setting. There is an 1889 specimen from Clifton, within this area, and Fairley (2004) reported that *Haloragis exalata* subsp. *exalata* var. *exalata* was *rediscovered in 1992 and is now known from three locations in the Illawarra (Stanwell Park, Coalcliff, Coledale) and from Berry where it grows on margins of rainforest and along damp creek banks,* but it was not possible to obtain further information about these records, which are apparently not supported by herbarium specimens or DECC Wildlife Atlas records.

Shoalhaven River

A specimen collected by K. McDougall from the Shoalhaven River/ Bungonia Creek confluence appears to be *Haloragis exalata* subsp. *exalata* var. *exalata*, but plants of this taxon could not be relocated in this location in 2006.

Shoalhaven Gorge and Bungonia Creek -see under c)*Haloragis serra.*

Durras Lake, north of Batemans Bay

40 plants, mostly seedlings recorded in 2006 on road verge adjacent to an arm of Durras Lake.

Tuross Lake, south of Moruya

3 plants recorded in 2006, in a canopy gap created by a fallen *Casuarina glauca*.

Wagonga Inlet, west of Narooma

A large *Haloragis exalata* population (>500 plants) found in pasture on the edge of forest on a small freshwater drainage line flowing into Wagonga Inlet in 2006.

Nangudga Lake, south of Narooma

24 plants were found on a small creek flowing into Nangudga Lake in 2006, on creek edges and forest/pasture edges.

Corunna Lake, 8km north of Wallaga Lake

An estimated 300 plants, scattered in 9 locations around the northern shoreline (the only area searched) in 2004–5.

Mt Dromedary

Existing tracks on Mt Dromedary searched in 2005 but no plants, nor any likely riparian habitat seen. However, when historical collections were made (1880, 1889), the mountain was extensively disturbed by goldmining, and numerous additional tracks and clearings, now over-grown, would have been present, and may have provided habitat. Alternatively, the reference to Mt Dromedary on the 1889 specimen may refer to the district rather than the mountain itself. The “Tilba Swamp” of one historical record probably refers to Bobundara Swamp, which is now on farmed private property, and has not been searched.

Wallaga Lake

Haloragis exalata subsp. *exalata* var. *exalata* was recorded in 2001 during a weed survey of Snake Island in Gulaga National Park, in the delta of Dignams Creek, where it enters Wallaga Lake. In 2004–05 we undertook surveys of parts of Snake Island and the Wallaga Lake foreshore where we found several sub-populations varying from one to several hundred plants scattered around most of the shoreline.

Dignams and Narira Creeks

Dignams Creek rises south and west of Mt Dromedary. We undertook a survey of the non-tidal section of Dignams Creek, walking along 6 km of creek frontage. Dignams Creek above the tidal limit carried several hundred plants scattered along 3 km of creek frontage, though an additional 3 km searched immediately upstream had no plants. Narira Creek, the other major tributary of Wallaga Lake, was searched up to the limit of navigability by boat. By contrast with Dignams Creek, most of the Narira Creek catchment and banks have been cleared for dairy farming, so surveys of the non-tidal section were considered unlikely to be productive.

Cuttagee Lake, 12 km south of Wallaga Lake

Four sub-populations of 3, 30, 50 and c. 100 plants were located in 2004–05, and have been monitored through several changes in lake levels since then, varying in total population size between 27 and 200 plants.

Geehi Dam, 3–4 km west of the Kosciuszko Main Range (1100m elevation)

In 2002 *Haloragis exalata* subsp. *exalata* var. *exalata* was discovered scattered on road verges and a powerline easement (ngh environmental 2003a). Initial surveys were confined to the verges of roads and other disturbed sites around the dam.

In December 2003 the response of *Haloragis exalata* to the January 2003 Kosciuszko wildfires was observed (ngh environmental 2003b). Ten months after the fires thousands of seedlings were found extending up slopes above roads near the dam in burnt forest, but on an unburnt powerline easement there was no apparent change in plant numbers. The bed of the Geehi River was surveyed over a limited area immediately below the dam wall, where it has been substantially modified by loss of flow and weed invasion but no *Haloragis exalata* was found.

A third survey in June 2005 extended the occurrences of *Haloragis exalata* up to 14 km from the dam wall along Olsens Road, and established that the plants extend for more than 50 m above roads and tracks in burnt forest. The populations originally detected on road verges and probably unaffected by the fires were still present.

b) Current distribution of *Haloragis exalata* subsp. *exalata* var. *laevis*

Gooseberry Island, Lake Illawarra

In July 2005, after a reasonably thorough search of the entire island shoreline and some of the interior, we recorded only 20 plants, in 3 clumps, spread over 150m of shoreline in canopy gaps between the *Casuarina glauca* fringe and the interior rainforest. This is the only extant population known of this taxon. Weed infestations could represent a substantial threat.

c) Some current locations for *Haloragis serra*

Shoalhaven Gorge

A specimen originally identified as *Haloragis exalata* subsp. *exalata* var. *exalata* was collected from the walls of the Shoalhaven Gorge in 1985 (CANB specimen). Habitat notes state “Steep rocky slope, gully edge, NE aspect. Skeletal soil on meta-sediments. Open forest, *Eucalyptus tereticornis, Olearia viscidula, Myoporum montanum*”. The collection is from 400m elevation, substantially above the level of the Shoalhaven River at this point (140m), and so not riparian. The specimen was subsequently re-determined as var. *laevis*, but on appearance and habitat it appears to us more likely to be *Haloragis serra.*

Tallowa Dam

A similar specimen (held at NSW Herbarium), was collected in 1988 below Tallowa Dam. We relocated this population - 15 plants growing among rock scrub in skeletal soils on sandstone, well above the riparian zone. Dr Peter Wilson confirmed that our collection from this site, and the 1988 specimen, are both *Haloragis serra.*

Bungonia Creek

In 2004 *Haloragis exalata* subsp. *exalata* var. *exalata* was recorded by one of us (JM) in the bed of Bungonia Creek (ngh environmental 2005). A re-survey of this area in January 2006 found that the scattered large fruiting plants present in the creek bed were, in fact, *Haloragis serra*, despite the riparian habitat being more typical of *Haloragis exalata. Haloragis serra* of more typical compact habit also occurs on limestone pavement at the top of the gorge.

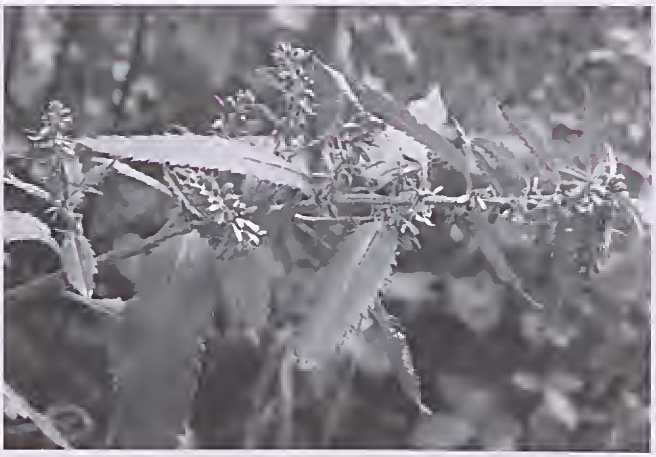

Fig. 2. *Haloragis exalata* subsp. *exalata* var. *exalata* at Dignams Creek, near Bermagui. Stems and leaves are scabrous. Reduced leaves in the flowering region have sparser teeth, similar to those of *Haloragis serra.*

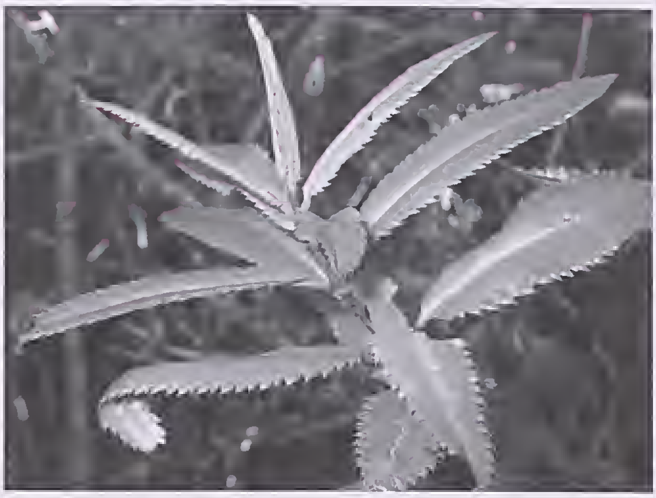

Fig. 3. *Haloragis exalata* subsp. *exalata* var. *laevis* at Gooseberry Island, Lake Illawarra. Stems and leaves are completely glabrous.

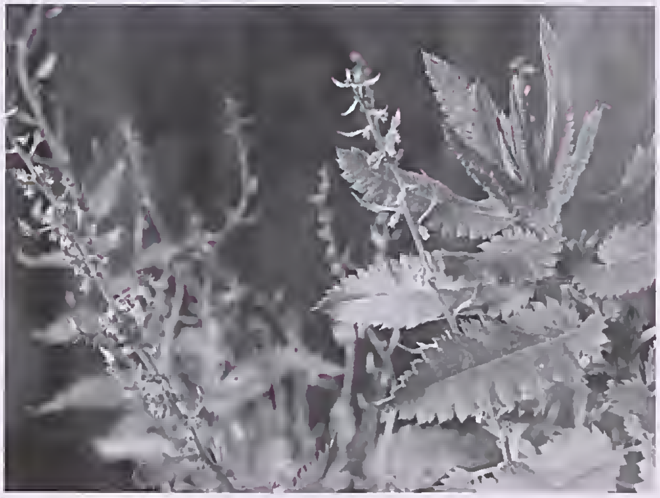

Fig. 4. *Haloragis exalata* fruiting plant at Geehi, showing the relatively broad leaves found in this population.

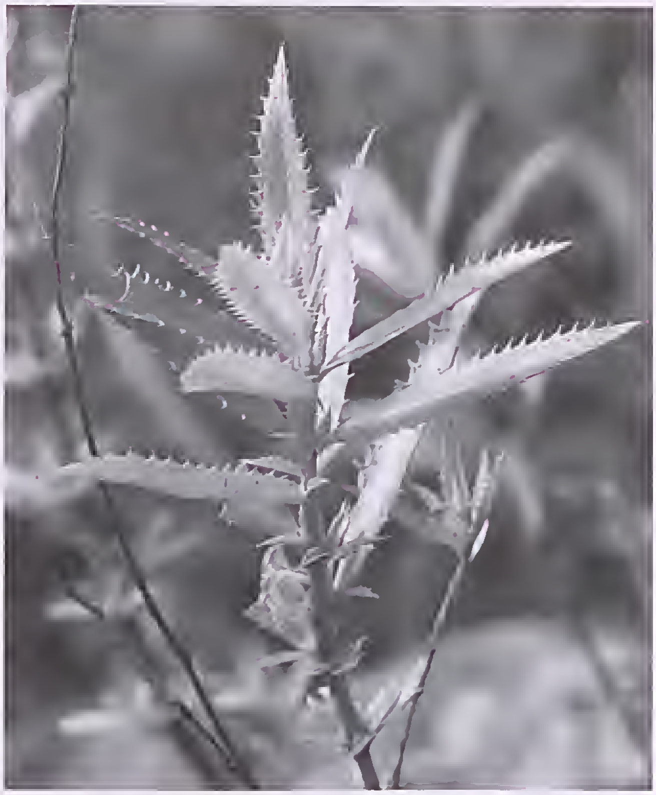

Fig. 5. *Haloragis serra* near Tallowa Dam, showing the relatively sparser and longer teeth on leaf margins.

Results

Distribution of Haloragis exalata subsp. exalata

The results of our surveys (Table 1a) show that *Haloragis exalata* subsp. *exalata* var. *exalata* currently occurs along the NSW coast from Coalcliff to Cuttagee Lake south of Bermagui, and in the Southern Tablelands at Geehi in Kosciuszko National Park. Coastal water bodies on the South Coast on which we could find no occurrences of *Haloragis exalata* were the Bermagui River estuary, Murrah Lagoon, Middle Lagoon, Wapengo, Barragoot, Nargal and Mummaga Lakes. Quite a number of south coast lakes remain unsurveyed, and in most of those which have been surveyed only part of the shoreline has been covered, so there is potential for additional populations to occur. Populations historically recorded in western Sydney and the Hunter Valley are not known to exist currently, though cannot be said to be locally extinct until targeted searches have failed to find them. We did not conduct searches in these areas. Nor did we survey the areas in Victoria where it has formerly been recorded.

In contrast, the distribution of *Haloragis exalata* subsp. *exalata* var. *laevis* is much more restricted (Table 1b). If specimens from the Shoalhaven River are *Haloragis serra*, as appears to be the case, the only known extant occurrence of this taxon is the single small population on Gooseberry Island in Lake Illawarra.

Within the current distribution of *Haloragis exalata* subsp. *exalata,* environmental disturbance by Europeans is likely to have been most intense, and to have operated over the longest period, in the Sydney and Illawarra areas. The Coalcliff and Gooseberry Island populations appear to be the least thriving of all those examined.

Variation between Geehi and South Coast populations of Haloragis exalata subsp. *exalata* var. *exalata*

We found morphological differences between Geehi and South Coast specimens identified as *Haloragis exalata* subsp. *exalata* var. *exalata.* These morphological differences include the shape and colour of stems, and differences in leaf shape, leaf indumentum and leaf arrangement (Table 2) (Figure 4). The population at Geehi is not tied to riparian habitat, but extends widely over at least the lower slopes within tall wet sclerophyll forest, a habitat quite dissimilar to that in which it occurs on the NSW South Coast. These differences and their disjunct distributions (separated by at least 170 km and 1100 m elevation), suggest that the Geehi population should be investigated as a possible discrete taxon.

Haloragis serra

Notes accompanying *Haloragis serra* specimens suggest that it occurs frequently, but not exclusively, in rocky sites, with an affinity for limestone (with specimens from Wee Jasper, Jenolan Caves, Abercrombie Caves and Bungonia Caves). There are also specimens from sandstone in Marramarra National Park on the Hawkesbury River (possibly influenced by calcareous midden material – Doug Benson pers. comm.) and at Tallowa Dam, Shoalhaven River (Table 1c), and other geologies (Warrumbungle Range, *skeletal clay loam on trachyte*). The majority of specimens come from the NSW Tablelands and Western Slopes.

In the absence of fruiting material the best distinguishing feature between *Haloragis serra* and *Haloragis exalata* appears to be the teeth of the leaf margin, which are widely spaced and excurved with an acuminate tip in *Haloragis serra* and more numerous, crowded and blunter in *Haloragis exalata* subsp. *exalata*, though reduced leaves in the flowering region approach those of *Haloragis serra* in appearance.

Growth form of Haloragis exalata subsp. exalata

Our observations suggest that *Haloragis exalata* subsp. *exalata* var. *exalata* is more a perennial forb than a shrub, despite its large size. It may reach over 2 m in height, though 1–1.5 m is more common. It does not form a permanent woody stem, but produces masses of stems from the base. Stems are relatively lax and layering has occasionally been observed in prostrate stems. Our observations of var. *laevis* are limited, but its morphology is similar.

Flowering and fruiting

In common with many Australian plants, timing of reproductive activity may be tied more closely to rainfall than to temperature or day length. Plants flowered and fruited through January–February in 2005 at Wallaga and Cuttagee lakes, but the following summer many plants had largely finished flowering by the end of December. It seems likely that the Geehi plants (at 1100m elevation) flower somewhat later in the season as a few still bore fruits in June 2005. Plants in full sunlight appear to be more likely to flower and set fruit than those in more shaded sites, and flower earlier. The inconspicuous flowers are believed to be wind-pollinated (A. Orchard, pers. comm.).

The fruits, each potentially containing up to four seeds, are shed very freely when the plant is brushed or shaken. In the coastal populations, following seed drop the terminal inflorescence withers and the plant produces new lateral branches lower on the stem. New stems also arise from the base of the plant, with vigorous growth continuing through the winter. In the Geehi plants new growth from laterals appears to be rare and in most cases the stems die back completely after fruiting to be replaced by new stems.

Table 2 Morphological differences between NSW South Coast and Geehi specimens of *Haloragis exalata* subsp. *exalata* var. *exalata*

Character	Typical coastal plants	Geehi plants
Stems	Conspicuously red stems, 4-ridged	Stems more often green, less square in profile
Leaf shape	Narrower, longer leaf: length:width ratio averaged 4.66:1 (range 10.5–12 x 2.4–2.5cm) on a typical plant from Corunna Lake.	Shorter, broader leaf: length:width ratio averaged 1.97:1 (range 8.5–9 x 4.5–5cm) on a single representative plant.
Leaf indumentum	Short stiff hairs, rough surface texture.	Indumentum shorter and denser, giving a velvety texture.
Leaf arrangement	Leaves mostly opposite, reducing in size and becoming alternate only in the flowering region.	Leaves may be alternate from the base on new shoots, shoots with opposite and shoots with alternate leaves may occur on the same plant, as well as reduced, alternate leaves in flowering region.

Seed germination

The fruits are indehiscent, so seed presumably does not germinate until the surrounding fruit has broken down sufficiently to allow water penetration. As the outer covering is quite hard, this may take some time. At Cuttagee Lake where plants fruited profusely in the summer of 2004–05, no seedlings were observed to have germinated by the following spring. By summer however, more than 30 seedlings were present.

In one of our small experiments, two samples of 100 freshly collected fruits were sown, one watered daily, and the other kept permanently flooded to simulate lake margins conditions. Germination took about three weeks and was poor in both, with a total of only 5 seedlings emerging from 200 fruits. The seed punnets were maintained for a further six months, with no additional germination occurring. In a dissected sample of 20, half the fruits were found to contain no seed, which may partially explain the poor germination rates.

Seed dispersal

Seed appears to be transported by water and fruits have been found to be quite buoyant. In a buoyancy experiment, 100 ripe fruits were agitated in water and left to settle – 72 were still floating after 30 hours. A feature of many coastal colonies is the arrangement of plants in distinct lines which appear to represent water levels during high stand events in the lakes or floods in the creek. It seems probable that this patterning is produced by the deposition of waterborne seeds.

Other species of *Haloragis* have been observed to be myrmecochorous (A. Orchard, pers. comm.) and it is possible that ants also collect and store the fruits of *Haloragis exalata* subsp. *exalata*. However, if it occurs it is likely to be a minor factor in coastal populations, as ant dispersal only occurs over small distances.

Herbivory

Some browsing was observed at a small number of sites but *Haloragis exalata* subsp. *exalata* does not generally seem to suffer serious damage by vertebrate herbivory, though occasional browsing by swamp wallabies (*Wallabia bicolor*) of some individual plants within a population may occur. The two small Narira Creek colonies were heavily browsed on each of the three occasions they were seen, but appeared to be persisting despite this, at least over the period 2001–2005.

Damage by insects appears to be rare, though a few plants on Dignams Creek carried large numbers of a small iridescent blue beetle (*Altica* sp. Galerucinae: Chrysomelidae) and up to 50% of the area of many of the leaves had been consumed.

Plant longevity

The longevity of the plants is currently unknown. It seems likely that an individual plant would continue to produce new stems until killed outright by an event such as fire or prolonged inundation, or possibly in some locations until shaded out by increasing canopy density. Plants on the upper banks of Dignams Creek seem likely to have germinated after the last major flood in December 1992, since there have been no floods since that time which would have reached the upper bank level. These plants would be 14 years old at the time of writing (2007).

Habitat preferences and recruitment

Populations of *Haloragis exalata* subsp. *exalata* are largely associated with some form of disturbance which temporarily bares the ground and often results in a degree of canopy breakdown and an increase in light intensity at ground level. The disturbance mechanisms on coastal sites include erosion and deposition by floodwaters, prolonged inundation during periods of lake closure, gap creation through weed control activities and canopy tree collapse.

On coastal sites *Haloragis exalata* subsp. *exalata* tends to occupy the most moist and naturally fire protected areas in the landscape, and it is improbable that fire is a significant disturbance factor here. The population on Dignams Creek is almost entirely confined to the zone subject to occasional flood disturbance. Numerous plants have colonised stream bed and anabranch alluvial deposits. Other individual plants and colonies are on higher banks but still within the zone affected by major floods. A few plants on the edges of a track which fords the creek are above flood level.

The populations of Corunna, Wallaga and Cuttagee Lakes are largely associated with sites affected by prolonged lake-shore inundation, with the occasional colony in areas of human disturbance such as roadside drains. All three lakes are classed as Intermittently Closed and Open Coastal Lakes and Lagoons (ICOLL) and alternate between tidal phases and phases when they are closed to the ocean by sandbars. As a result of rain during the closed phase the lakes may stand for periods of several months at considerably higher levels than are attained at the highest tides. The resulting inundation by saline water commonly results in the death of shore plants unable to tolerate these conditions (Figure 6).

Corunna, Wallaga and Cuttagee Lakes have each undergone lengthy periods of high water levels interspersed with lower lake levels during the four dry years, 2002–2006. The size of some drowned trees suggests that similar inundation events have not occurred for about 20 years. *Haloragis exalata* subsp. *exalata* has been observed predominantly in those zones where inundation has killed vegetation, creating canopy gaps and bare ground and, in many cases, where it has resulted in the deposition of a line of debris. It frequently occurs with a number of native and exotic asteraceous species (*Senecio linearifolius, Senecio minimus, *Aster subulatus, *Cirsium vulgare, *Conyza albida*), which also exploit these gaps in the lake shore vegetation (*denotes exotic species).

Waterways that are permanently open to the sea generally lack such canopy gaps and searches of the Bermagui and Murrah River estuaries and Wapengo Lake, all permanently open, located no *Haloragis exalata.* A large population was found on one permanently open waterway, Wagonga Inlet, although in this case the population was not on the lake margin, but associated with a small freshwater gully passing from forest into a cleared paddock, just above tidal level.

A small number of plants found on the normally tidal Tuross Lake were associated with a canopy gap created by a fallen *Casuarina glauca* tree, adjacent to a rainforest stand and well above the potential high stand level. On Gooseberry Island *Haloragis exalata* subsp. *exalata* var. *laevis* plants are associated with patches where **Lantana camara* has died or been removed, within the fringing *Casuarina glauca* forest and apparently above normal high water level.

The availability of moisture may limit the extent of coastal colonies. Prior to drought-breaking rains in July 2005, plants on the drier upslope margins of the lake shore colonies were observed to be suffering water stress, wilting before any other species in the vicinity. Only at Geehi are plants widely dispersed, in a habitat which is uniformly relatively moist.

At Geehi disturbance mechanisms include fire, baring of soil by human and animal excavations and creation of canopy gaps on powerline easements and along roads.

Response to flooding

A flood event affecting the Wallaga and Cuttagee Lake catchments in July 2005 opened both lakes to the sea after a period of about 48 hours of very high water level. Many plants of *Haloragis exalata* subsp. *exalata* were totally or partially submerged during this period. At a Cuttagee Lake site adjacent to a tributary creek where the water around the plants was fresh, the plants appeared to be unaffected by their immersion, but a site near the mouth of Wallaga Lake, remote from floodwater inflows and where the inundation would have been by saline water, the plants were severely burned.

Ten weeks after the flood event all above-ground portions of these Wallaga Lake plants were dead; six months later these plants showed no signs of resprouting, nor was any seedling germination evident. Plants above the high water mark appeared to have been burned to some extent by wind-blown salt, but were gradually recovering, and in some cases flowering sparsely. It appears that the plants are not highly salt tolerant; this may partially explain their distribution around the lake margins, which is frequently in areas of freshwater inflow.

Following the same flood event, plants in the stream-bed of Dignams Creek were found to have been wholly submerged, partially flattened and severely battered, to the extent that leaves were being shed. No plants had been wholly dislodged and a week after the flood peak the growing tips of flattened stems had reoriented upwards. Six months later these stream-bed plants had fully recovered, with new lateral shoots growing up from the flattened stems, even in plants whose root systems had been partially uncovered (Figure 7).

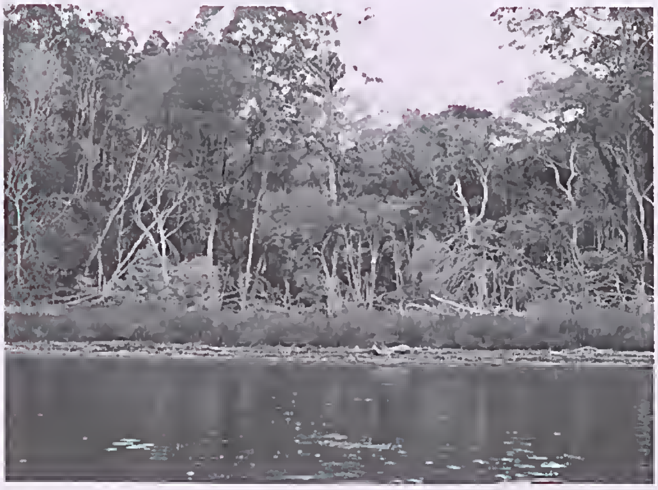

Fig. 6. *Haloragis exalata* habitat on Cuttagee Lake, south of Bermagui. Plants are located within the dead vegetation behind the strandline belt of *Suaeda australis.*

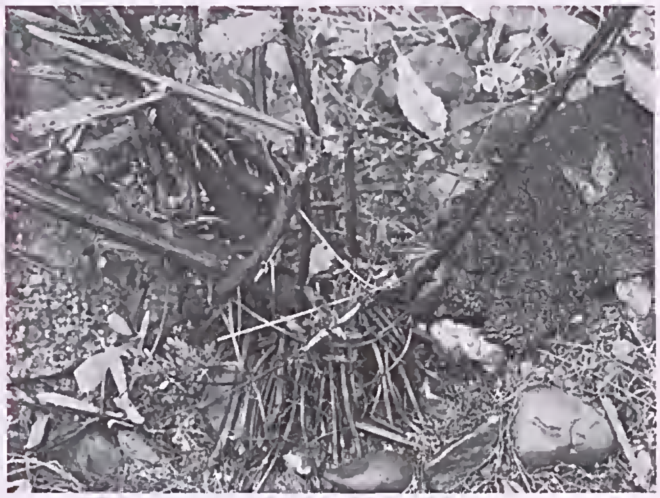

Fig. 7. *Haloragis exalata* subsp. *exalata* var. *exalata* at Dignams Creek after flooding, with the base of the plant well anchored in the loose substrate.

In July 2006 rain resulted in a high stand event which inundated all populations at Cuttagee Lake for 25 days (until the lake was artificially opened). All but the most upslope plants progressively died - by February 2007 only 7 mature plants and 20 seedlings remained on the lake shore. The population had peaked in early 2006 at more than 200 plants.

Response to fire

At Geehi, various disturbance factors are operative, but the most important agent is fire, the January 2003 Kosciuszko wildfire having established conditions for the germination of a very large population extending discontinuously over at least 14 km. Given the dissection of the terrain, the effects of any one fire are likely to be spatially variable and within this patchy distribution *Haloragis exalata* subsp. *exalata* can be present in thousands. The density was found to vary considerably. In some locations *Haloragis exalata* is a dominant species in the regenerating understorey, particularly on a burnt powerline easement, where a tree canopy was lacking. It occurred both in areas which had burnt at high intensity (indicated by death of the canopy Alpine Ash, *Eucalyptus delegatensis*), and areas where the understorey had been burnt, but with no canopy scorch. On the basis of limited observations in two areas, it appeared to be more abundant in a lightly burnt area which had a more grassy understorey, compared with a high fire intensity site, where there was very dense regeneration of tree and shrub seedlings (mostly *Eucalyptus delegatensis* and *Daviesia latifolia*). However it is not clear whether this difference relates directly to the fire intensity, to pre-fire differences in the understorey, or to differing density of the post-fire regeneration.

The size of the response to this fire implies considerable longevity for seeds in the soil seedbank. While fires of the intensity and extent of January 2003 are uncommon, fires occurred in the Geehi Dam vicinity in summer 1972–3, and in 1993, 30 years and 10 years previously (Craig Smith, Ranger, Geehi/Jagungal, pers. comm.).

The formation of roads and tracks results in canopy disruption and exposure of bare earth. *Haloragis exalata* occurs on road verges at Geehi Dam, Dignams Creek, Wallaga Lake, Corunna Lake and Coalcliff and small numbers of seedlings have been observed in soil disturbed by animal excavations at Geehi and Corunna Lake. Our observations suggest that in the absence of fire a small number of plants would persist at Geehi in such disturbed sites as track verges, landslips and where soil is disturbed by wombat excavations.

Discussion

Rarity

The distribution pattern and apparent habitat preferences of *Haloragis exalata* subsp. *exalata* pose interesting questions. Recorded populations are widely disjunct, with 500 km separating the Victorian and Geehi populations and 170 km between Geehi and the nearest NSW coastal population. There are substantial differences in habitat between the coastal and Geehi populations.

Despite its overall 'rarity' within its extent of occurrence, *Haloragis exalata* subsp. *exalata* can be locally abundant. It fruits profusely (though seed production may be lower than appearances suggest as some fruits are empty), its seeds must have considerable longevity and it is capable of regenerating in dense stands when conditions are suitable. Once established it competes fairly successfully with exotic weeds and it does not appear to be subject to much herbivory by either vertebrates or invertebrates. It is evidently advantaged, at least in the long term, by disturbance. Indeed the apparent rarity may be to some degree an artefact of observation, as it is obvious and likely to be observed in the landscape only after appropriate disturbance events and may otherwise be present only or mainly in the soil seed bank. Given these characteristics it is surprising that *Haloragis exalata* subsp. *exalata* is not more widespread across south-eastern Australia. In New Zealand the closely related *Haloragis erecta* is widespread and abundant, and according to Forde (1964) *almost becoming a weed in some local areas.*

Forde's (1964) thesis that the closely related *Haloragis* species of Australia, New Zealand and the Juan Fernandez Islands (off Chile) represent disjunct components of a single species complex in evolution is worth consideration. It is possible that the restricted geographic range of *Haloragis exalata* subsp. *exalata* may be 'incipient' rather than 'relictual', (to use the terminology of Rabinowitz 1981); that its rarity is that of a plant still at a relatively early stage of colonisation and speciation in south-eastern Australia. The coastal habitats of the species are of recent geomorphology, formed since the post-glaciation inundation of coastal valleys within the past 20,000 years, and its high altitude Geehi habitat is hardly likely to have supported the current suite of species during glacial phases.

Threatening processes

The majority of NSW *Haloragis exalata* subsp. *exalata* populations occur within conservation areas. The Geehi plants are within Kosciuszko National Park and Gooseberry Island is in Berkeley Nature Reserve. The occurrence of the taxon (if present) on the Shoalhaven River is likely to be within Morton National Park or Bungonia State Conservation Area. Around the South Coast lake-shores colonies occur on a diversity of tenures, but the majority are on public land managed by the NSW Department of Environment and

Climate Change and the Bega Valley and Eurobodalla Shire Councils. Three riparian populations are on freehold tenure.

We consider that the two greatest threats are displacement by weeds, and cessation of the disturbance-inducing processes upon which the plant appears reliant. Some of the coastal sites where *Haloragis exalata* subsp. *exalata* occurs, particularly Gooseberry Island, Coalcliff, Snake Island and the banks of Dignams Creek, are moderately to heavily infested with environmental weeds, particularly **Lantana camara, *Asparagus asparagoides, *Delairea odorata, *Araujia sericifera* and **Rubus ulmifolius*. The existing *Haloragis exalata* populations at these sites presumably established in the presence of these weeds, though perhaps after they, like the canopy of native shrubs and trees, had been damaged by flooding, clearing or weed control activities. *Haloragis exalata* appears to be a strong competitor with weed species. Nevertheless at some sites weed invasion is at a relatively early stage and, without effective intervention, *Haloragis exalata* may eventually be seriously disadvantaged. That few plants could be found in the Illawarra populations suggests that it is faring less well in these relatively weedy areas, compared with the less degraded coastal habitats of the far South Coast. The only population of var. *laevis* is probably already suffering adversely from competition from dense **Lantana camara* infestations on Gooseberry Island. An additional potential threat is of destruction of plants during weed control operations.

Maintenance of recruitment regimes

As discussed above, different disturbing processes operate at different sites. There is no reason to suppose that the fire regime to which the Geehi population is subject will change, so as to diminish the requisite disturbance. Likewise floods will continue to advantage riparian and lake shore populations of *Haloragis exalata*, although both flood and fire frequencies could be affected by anthropogenic climate change.

Inundation-induced disturbance of lake shore vegetation can only occur if the responsible authorities leave the lakes to stand at high levels for lengthy periods. Such high stands are contentious since they damage or render temporarily unusable such assets as jetties, roads, caravan park sites and pastures. At the time of writing there was a proposal to construct breakwaters at the entrance of Lake Illawarra with the intention of reducing sand in-flow and thereby reducing or eliminating periods when the lake is closed. If these works are constructed and function as intended, the Gooseberry Island population may be disadvantaged, and some active manipulation of its habitat may be required to offset this.

The populations along the lakes and estuaries of the far South Coast appear to have persisted through more than a century of partial catchment modification, and may currently be at unusually high levels due to high stand events over the past four years of drought. Its wide distribution around several lakes and estuaries offers a degree of insurance against events or processes which might destroy individual colonies and suggests that recolonisation of suitable sites would be likely to occur eventually, without the need for human intervention. However, if riparian colonies are dependent upon replenishment by seed carried from upstream sites, it may be important to ensure that the most upstream colonies are conserved and protected.

Conservation assessment

To be eligible for listing under IUCN Red Book guidelines *Haloragis exalata* subsp. *exalata* needs to satisfy one of the following five criteria:

- Criterion A (population reduction): In NSW recent survey effort has dramatically increased the number of known populations, with plant numbers being very large in some of these. *Haloragis exalata* subsp. *exalata* does not satisfy this criterion.
- Criterion B (geographic range): Recent discoveries of the taxon have also increased the geographic range, which has been extended out to the Snowy Mountains, although truncated at the northern end of the range through probable loss of populations in the Sydney area. There are also no recent records from the Hunter Valley. The range would exceed 20 000 km², the upper limit for consideration as vulnerable. Within its range the taxon is naturally fragmented in distribution. It would be eligible for listing as vulnerable if the area of occupancy within its range could be shown to be <2000km², the number of locations at which is it known is 6–10 and it undergoes extreme fluctuations in numbers of mature individuals. The first two points may be true, although in the absence of a thorough survey of the Snowy Mountains there is no knowing how large an area it may occupy there. It is quite likely that it occurs in other areas besides the Geehi Valley. The number of locations depends on the definition of location, but if each lake from which there is a formal record (voucher specimen or DECC Wildlife Atlas record) is taken to be a single location, and the Geehi population as another, then the current number of known locations is ten for this taxon, with another three reported locations between Berry and Stanwell Park for which no data is available. Although it appears to undergo large population fluctuations, the guidelines for interpretation of the IUCN criteria specifically exclude organisms with a "boom and bust" life cycle such as *Haloragis exalata* subsp. *exalata* from being considered under this criterion. It therefore does not satisfy sufficient points under criterion B.
- Criterion C (small population size and decline) and D (very small or restricted population): *Haloragis exalata* subsp. *exalata* var. *exalata* does not satisfy these criteria.
- Criterion E (quantitative analysis): insufficient data are available to apply this criterion.

A reassessment of the level of threat facing *Haloragis exalata* subsp. *exalata* based on the IUCN criteria using our recent data suggests that *Haloragis exalata* subsp. *exalata* var. *exalata* may not now satisfy criterion for listing as Threatened, at least in NSW. Further survey effort in Victoria would be required to determine the current status of populations there.

The same is not true of *Haloragis exalata* subsp. *exalata* var. *laevis* however, which is restricted to a local population of 20 plants on Gooseberry Island in Lake Illawarra, and would appear to be eligible for listing as critically endangered (with a known population of <50 mature individuals).

A National Recovery Plan for *Haloragis exalata* subsp. *exalata* (Carter, in prep.) recommends ensuring the continuance of natural or anthropogenic disturbance regimes applicable at each site, undertaking weed control, ongoing monitoring of all populations, further survey and research into the reproductive biology of the taxon. These recommendations are particularly urgent with respect to *Haloragis exalata* subsp. *exalata* var. *laevis*, though the Recovery Plan does not make this point.

There is much still to be learned of the life history and ecological role of *Haloragis exalata* subsp. *exalata*. Closer study may yield useful insights applicable to a whole class of plants sharing its status of apparent rarity and dependence upon stochastic disturbance-inducing events, many of which are also listed as threatened in NSW.

Acknowledgements

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Vegetation-soil relations in a highly sodic landscape, Yelarbon, southern Queensland

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Soil and vegetation data were collected from a sodic-scald near Yelarbon in southern Queensland. The surface of the landscape includes relatively light textured pedestals of the A-horizon with slightly alkaline pH and slopes leading down to scalded basement representing the surface of the strongly alkaline B-horizon. The strongest gradient within the floristic patterns was associated with wetland vegetation in drainage lines, but a secondary and orthogonal gradient was related to soil pH, which was probably a function of lower alkalinity on the more stable and weathered A-horizons. There were few significant differences between soil or vegetation characteristics from plot data comparing parts of the landscape with differing historical grazing regimes. Sites included stock routes heavily grazed between the 1920s and 1970s, and subsequently almost ungrazed; and grazed paddocks that have had moderate use throughout this period. There is clear evidence that the area is naturally active in terms of erosion and deposition during flooding regardless of grazing.

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Introduction

High sodicity and/or salinity are a prominent feature of inland Australian landscapes (Chartres 1993). While these characteristics are a function of natural processes, their significance increases when they lead to land degradation such as ‘scalding’, in which the surface horizons are removed, exposing chemically and/or physically hostile subsoils.

Scalds in eastern Australia generally develop from removal of surface soil (A horizon) and exposure of subsoil (B horizon) via wind- or water-driven sheet erosion. Scalds in southern inland Queensland are frequently associated with natural alluvial features often on the rarely flooded margins of floodplains (Land unit 66, Galloway *et al.* 1974; Land Unit 35, Dawson *et al.* 1974; Land unit 8, 13, Mills *et al.* 1990). Despite saline or sodic-scalds being relatively common in semi-arid Australia, there are few studies describing the vegetation associated with these areas (Kreeb *et al.* 1995), other than general land resource surveys. At Yelarbon in southern Queensland, there is a particularly prominent scald known locally as the ‘desert’ and this paper presents a detailed quadrat survey of both the scalded land and the surrounding area.

Sodicity and salinity are often confused because most saline soils in eastern Australia are also sodic, i.e. have a high proportion of sodium in relation to calcium, magnesium and potassium. The associated presence of high chloride and sulphate are the most common contributors to high salinity. Sodicity is generally a feature of subsoils rather than surface horizons, and sodic texture-contrast soils are widespread in eastern Australia (Rengasamy and Olsson 1991). Scalds with exposed sodic materials demonstrate crusting to hardsetting characteristics, with limited moisture infiltration (thus further propagating sheet erosion). Germination and re-colonisation by vegetation is limited by both physical and chemical factors (Ringroase-Voase et al. 1989; Qadir and Schubert 2002).

Despite a fairly detailed understanding of the physical and chemical processes within sodic soils that render them susceptible to degradation (Qadir and Schubert 2002), there are few systematic studies of the relationship between vegetation and sodic soils and the relative importance of intrinsic factors and grazing management. Vegetation patterns on sodic soils in Zimbabwe have been explained in relation to natural landscape processes as they determine soil condition without any consideration of land-use (Dye and Walker 1980). Kreeb *et al.* (1995) suggested that sodic-scalds in northern New South Wales are not primarily a product of land-use but result from deposition of sodic salts from groundwater and their accumulation as soils dry out in a seasonally arid climate.

The design of this survey in the Yelarbon sodic-scald capitalised on contrasting land-use either side of stock route fence-lines to assess the relative impact of natural processes and management on surface features, soil chemical conditions and vegetation patterns.

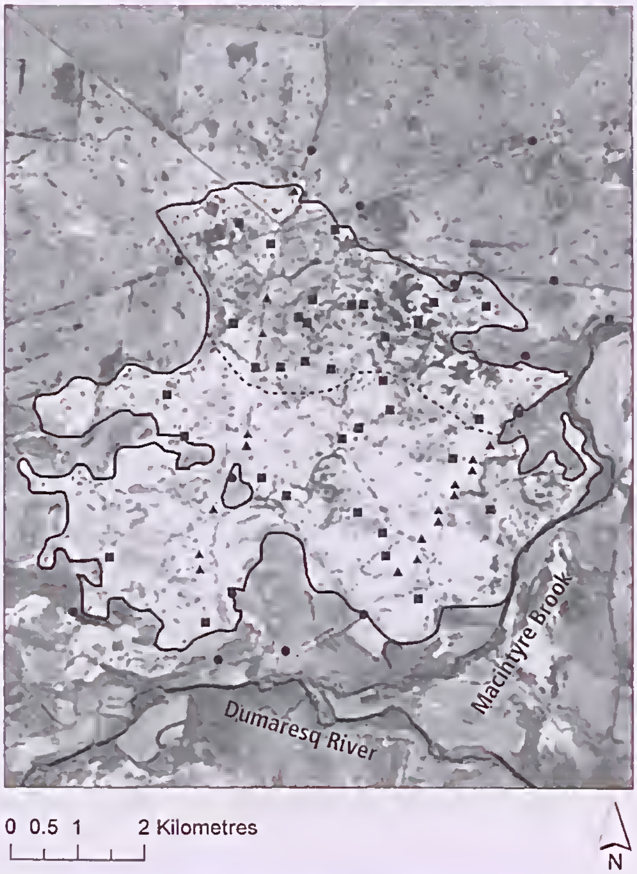

Fig. 1. The Yelarbon sodic-scald area as delineated by Queensland Herbarium mapping (regional ecosystem 11.5.14, Sattler and Williams 1999) on 2001 landsat imagery. The white scalded areas represent the exposed A_2 horizon. Outlying areas of scalded soils are evident to the west of the main area. Yelarbon township is evident in the northern part of the sodic-scald. Context plots are indicated as circles, paired stock route comparisons as triangles and other sodic-scald plots as squares. Sites classified as 'upper catchment' are north of the dashed line.

Study area and land use history

The barren nature of the sodic-scald at Yelarbon (Fig. 1) gave rise to it being referred to as the 'desert' (Isbell 1957; Thwaites and Macnish 1991). It is clearly visible on remotely-sensed imagery and is approximately 34.4 km^2, although there are outliers of similar scalded land types to the west of the main area, and inliers of less extreme land types within the broad envelope (Fig. 1). Despite its local name, the climate is only subhumid, receiving a mean annual rainfall of 595 mm, with only a slight seasonal bias to the summer months (65% between October and March). The nearby town of Goondiwindi has mean monthly minimum temperatures between 4.9°C and 20.1°C and mean monthly maximum temperatures between 18.1°C and 33.4°C. The area has low relief and lies to the north of the junction of Macintyre Brook and the Dumaresq River, the latter forming the Queensland-New South Wales state border.

The lower parts of the Yelarbon sodic-scald comprise recent ox-bows and related active features, while the higher parts are older, less active alluvial plains, with relict flowpaths still evident. Major flooding events since 1925 were in 1956 and 1976 (flood-gauge height greater than 10.8 m at 'Bengalla', 9 km downstream from the junction of Macintyre Brook and the Dumaresq River).

The intact soils are Grey to Brown Sodosols and typically have a clay loam, moderately acid to neutral A-horizon with a strongly alkaline, highly sodic, medium clay subsoil with ESP (exchangeable sodium percentage) values between 40 and 90% (Isbell 1957; Thwaites and Macnish, 1991; A. Biggs unpublished data). Chloride content is about 500 mg/kg and subsoil EC varies from 0.5 to 1.5 dS/m (1:5 soil:water extract). Surface pH ranges from 5.5–6.5 and subsoil pH varies from 8–11. Bleached A2 horizons are variably present. . Large amounts of both soft and hard carbonate materials are present in the subsoils and exposed in eroded areas. The high pH coupled with extreme ESP suggests sodium carbonate and sodium bicarbonate are the dominant salts in the soil. The soils have undergone extensive sheet erosion as indicated by bare ground and terraced topography resulting in the exposure of the B horizon (Fig. 2) and massive tunnel erosion in lower catchment areas (Fig. 3). Exposed sub-soils are crusting to hardsetting.

The accumulation of sodium has been attributed to upwards leakage of Great Artesian Basin (GAB) groundwaters along the Peel Fault offset by Knight *et al.* (1989) although Chen (2003) argued that the evolution of the area could have been driven by hydraulic heads associated with the Dumaresq River and Macintyre Brook. The combination of these pressure gradients downstream of two major streams provides a logical mechanism for upward vertical leakage. The confining beds of siltstone overlying the aquifer bearing Kumbarilla sandstones have been stripped away at Yelarbon, probably by a previous flow path of Macintyre Brook (Fig. 1), but are still intact to the east and west (Biggs *et al.* 2005). The contact between the sandstone basement and the overlying alluvium at Yelarbon is unclear, as the sandstones are often saturated and weak, thus resembling the sandy alluvia when drilled (Biggs *et al.* 2005). Extreme sodium levels (exchangeable sodium percentage ~90) and high proportions of both soft and hard carbonate segregations in the soils apparently reflects the Na–HCO$_3$-rich GAB groundwater in the area. Soils of the district do not normally evolve this chemistry, thus supporting the suggestion of a GAB contribution to the Yelarbon landscape. It is probable that the combination of transported salts from both streamflow and deeper GAB groundwater compound to produce the extreme environment of the Yelarbon desert.

The dominant tree on the sodic-scald is *Allocasuarina luehmanii* with *Melaleuca densispicata* common along drainage lines. Widely spaced hummocks of spinifex (*Triodia scariosa*) are also moderately abundant. There are ephemeral wetlands throughout the drainage lines of the scald and they were evident as free-water during the conditions of sampling after a wet summer.

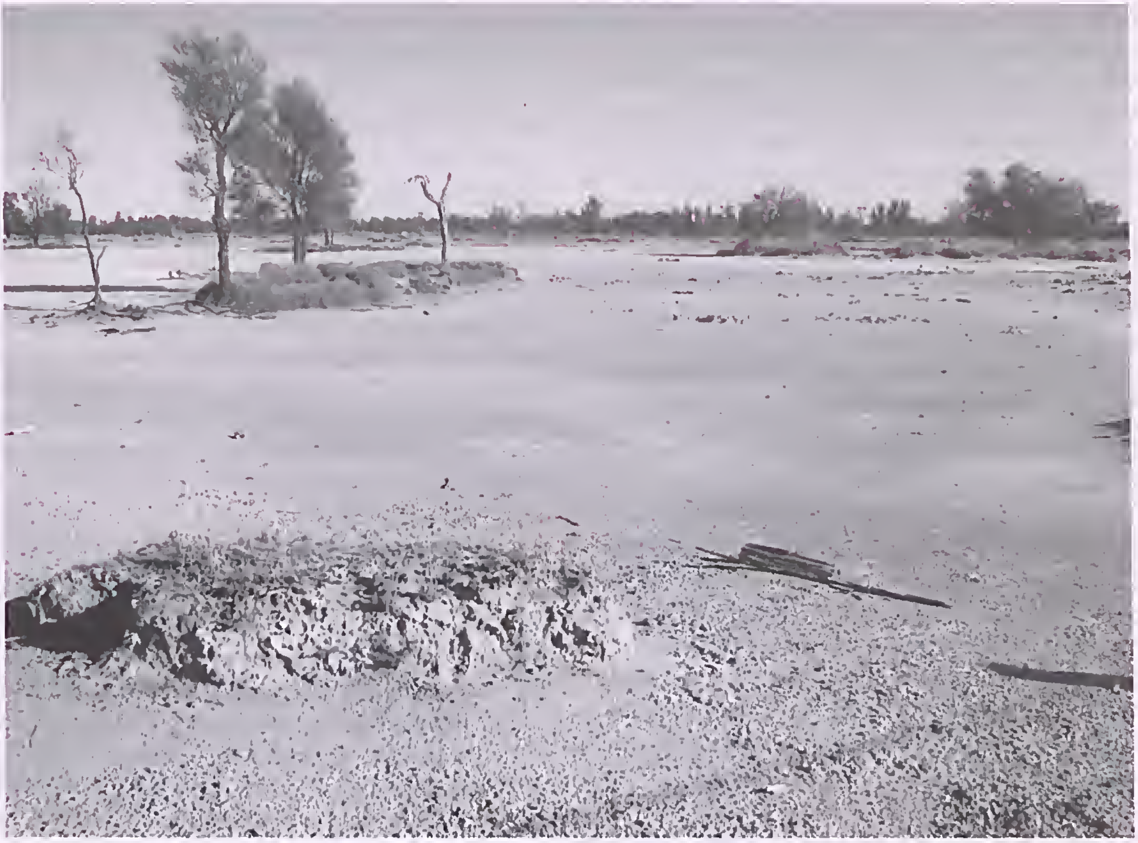

Fig. 2. The pedestaled surface feature and scalded sub-soil basement in a typical landscape scene at the Yelarbon sodic-scald.

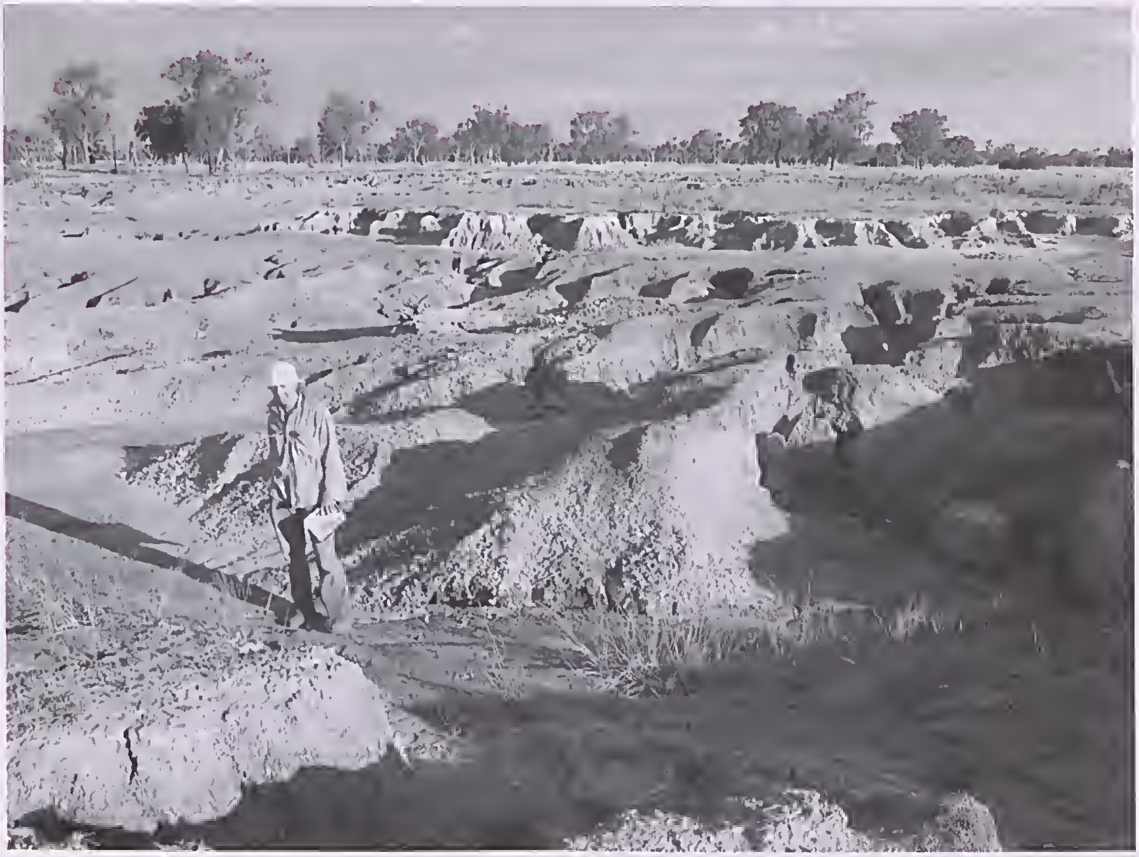

Fig. 3. Gully erosion in lower catchment areas at the Yelarbon sodic-scald.

The Yelarbon area was initially settled in the 1840s and would have been part of a large essentially unfenced pastoral holding from this time until closer settlement about the turn of the twentieth century. In addition to grazing by domestic stock the area would also have been subject to grazing pressure by rabbits, which were in sufficient numbers in the district to support a thriving rabbit works until the advent of myxamotosis in the 1950s (McLean 2002). Rabbits were never abundant on the sodic-scald because the thin top soils and unstable, hardsetting subsoils was unsuitable for warrens (J. Lennon pers. comm.), but the area would have experienced waves of rabbits migrating from adjacent densely populated areas to the east and south-west (D. Berman pers. comm.)

Two major stock routes approximately 50–100 m wide bisect the Yelarbon sodic-scald (Fig. 4). Land survey plans indicate that these stock routes were surveyed in 1898, and were fenced some time in the next 20 years (B. Wallace pers. comm.). The memory of long-term residents confirms very intensive grazing on the stock routes until trucking became the popular mode of transport from about the 1960s. The intensive use of the stock routes caused almost total removal of vegetative cover and scalding clearly evident on aerial photography (Fig. 4). Since this time the stock routes are only rarely used for grazing. The presence of the toxic plant *Bryophyllum delagoense* since the 1950s renders the stock route unsuitable for unaccustomed cattle. Thus the history of the stock route can be summarised as extensively denuded by stock, followed by a long period of grazing conditions conducive to recovery. All of the landholders were interviewed to describe their stocking rates and most of the area is relatively lightly stocked with the equivalent of 1 sheep to 1.7 ha or 1 heifer to 20 ha, with limited areas subject to even lighter stocking.

Methods

The following sites were selected:

Data from 36 plots (18 pairs) either side of the stock route–paddock fence-lines was collected to determine differences between sites with contrasting management histories. The paired sites were positioned within the sodic-scald land type at pre-determined regular locations along the stock routes where the vegetation was not wetland (free water at the time of sampling) and where there was no evidence of mechanical disturbance. The elongated plots were positioned parallel to the fence and were as close together as possible (typically 10 m).

34 extra plots were located within the grazed areas of the sodic-scald land type. These plots were positioned to represent the variation within the sodic-scald land type across its geographic range, including less common elements such as wetlands.

To provide a comparison to determine the extent to which the sodic-scald plots are distinct, 15 context plots in vegetation outside, but within 2 km of the sodic-scald were also sampled. Some of these context plots were within stock routes and others in grazed paddocks.

All vascular plants were recorded within a 50 m × 2 m quadrat and voucher specimens have been lodged at the Queensland Herbarium. Cover was recorded as the crown intercept along the central 50 m axis in the following categories: 0–1, 1–5, 5–10, 10–20, 20–30 m etc. and assigned as the mid-point of these categories. Sampling was conducted in March 2006 when conditions were ideal after a wet season of regular and substantial rainfall, although some winter annuals would have been poorly recorded. A brief plant survey in October 2006 records winter flowering annual species that may have evaded detection in the main survey. At ten regularly spaced points on the tape the following information was recorded:

- The depth of water;
- Soil penetration depth (an index of surface soil structure), measured by pushing an 8 mm blunt-ended steel rod with a horizontal cross-bar into the ground with upper body weight of a 90 kg person;
- Surface features as a) Pedestal (the upper horizontal land surface within the local area), b) Basement (scalded areas where the sub-soil basement is exposed after erosion), c) slope (erosion or deposition producing a graded surface between Terrace and Basement), or d) depression or drainage line;
- Ground cover type as a) vascular plant, b) cryptogam, c) litter or d) bare ground.

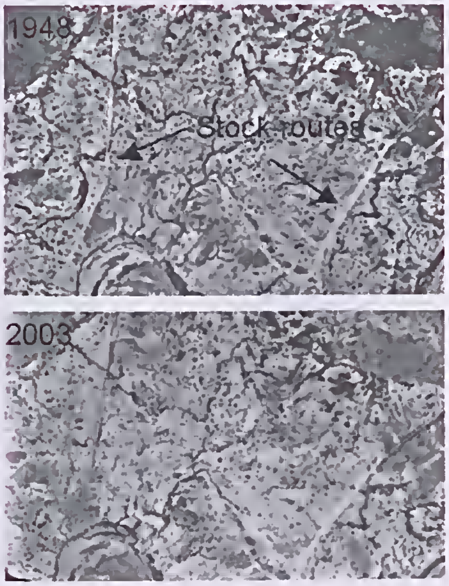

Fig. 4. Aerial photograph comparison of portion of the Yelarbon sodic-scald. The scalded nature of both the western and eastern stock route is clearly evident in the 1948 image. The scalded signature of the eastern stock route has persisted on the 2003 image.

A soil sample was taken from the highest point of each plot and assessed for pH using a TPS WP–81 pH meter (TPS Pty Ltd, Brisbane) with a 1:5 soil:water solution.

Nine plots spaced throughout the scalded area were selected to describe surface features of the non-wetland sodic-scald plots. At each of these sites a surface (1–5 cm depth) sample was taken and pH and soil texture according to the textural grades of McDonald *et al.* (1990) determined.

Data analysis

To describe the physical differences between the surface feature categories, box-plots were prepared of probe penetration depth for the sodic-scald sites only and comparisons made using the Kruskal-Wallis test where Z score differences greater than |2| indicated significant difference between means.

Plots were assigned to upper catchment and lower catchment after interpretation of elevation from 1:40 000 aerial photography using a stereoscope (Fig. 1). To determine the extent to which sodic-scald wetland plots (presence of free water) and non-wetland plots, and the context plots from the surrounding landscape are distinct from one another, their position in ordination space was examined. The site-species data were ordinated using non-metric multi-dimensional scaling using the default settings in DECODA (Minchin 1990) after adjusting cover scores to unit maxima. Exploratory analysis suggested that three dimensions accommodate the direction of all significant sample variables for the total dataset. A second analysis was conducted including the sodic-scald plots only and a two-dimensional solution was found to adequately represent the direction of sample variables. Vector analysis was used to examine the strength of correlation between the surface feature category cover scores (represented as separate proportions of the four categories), catchment elevation, pH and grazing index (0, stock route; 1, paddock), and floristic gradients represented by the ordination. The response of species in relation to environmental correlates was determined as average values in sites where the species are present after weighting using raw cover scores.

Stock route-paddock pairs were analysed separately using Wilcoxon's Test to compare count scores for the landscape and ground cover categories, mean soil penetration depth, the cover scores of nineteen species with a frequency greater than ten. A third ordination was conducted including only stock route-paddock pairs to investigate the potential role of grazing on floristic composition.

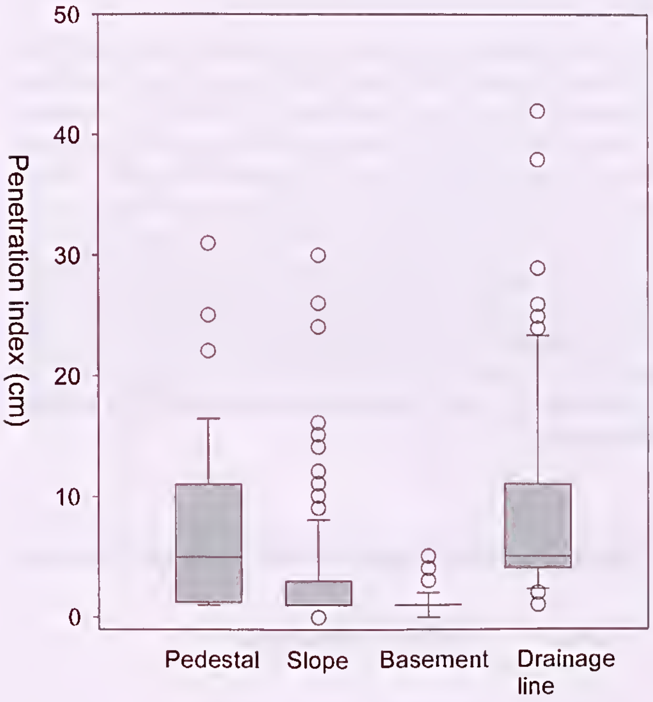

Fig.5. Box plots of the Soil penetration depth for the four microtopography categories. The median is identified within the box, limits of the box identify the 25th and 75th percentile, error bars identify the 10th and 90th percentiles, and circles are outliers. All pairs are significantly different based on Z value differences greater than |4| and an overall H value of 191.5 (P<0.001).

Results

Soil penetration depth was relatively high for the Pedestal surface feature, lower for Slope and almost zero for Basement—concomitant with the hardsetting surface found in the latter areas (Fig. 5). High median values for drainage lines indicate damp soils at the time of sampling.

Drainage areas have the highest vascular plant cover followed by pedestal, slope and basement. The latter has by far the greatest bare ground. Cryptogam cover is also low compared to slopes and basement (Table 1).

Soil-texture of the Pedestal was either light sandy clay loam or silty loam. The slopes were generally similar but could span a broader range from sandy loam to silty clay. The basement was always either light clay or medium clay. Soil pH graded from median values of 7.4 for the pedestal, 7.9 for the slope and 8.7 for the basement, with the highest value recorded being 9.6 (Fig. 6). The ordination of the 215 plant species in the 115 plots indicates a separation between the floristic composition of the sodic-scald plots and the surrounding landscape (Fig. 7), although the overlap indicates that some plots are related to non-scalded land types and that scalded land types occur outside the main area (Fig. 1). A high proportion of the total flora (71 species) was only recorded in the context plots. Despite the number of plots, only 64 species were only recorded from the sodic-scald area. Frequently recorded species that were faithful (absent from the context plots) to the sodic-scald plots include *Atriplex leptocarpa* (46 plots), *Portulaca australis* (17 plots), *Sarcozona praecox* (17 plots), *Triodia scariosa* (16 plots), *Plectranthus*

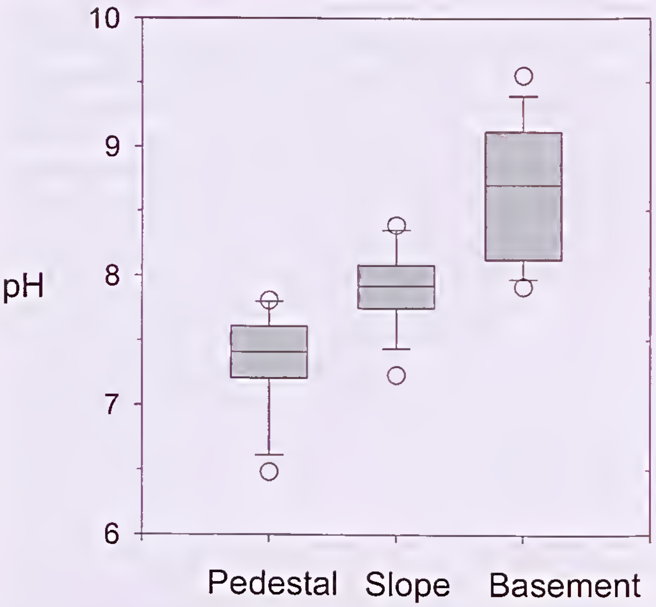

Fig. 6. Box plots of pH for three non-wetland microtopography categories. The median is identified within the box, limits of the box identify the 25th and 75th percentile, error bars identify the 10th and 90th percentiles, and circles are outliers. All pairs are significantly different based on Z value differences greater than |3.5| and an overall H value of 17.8 (P<0.001).

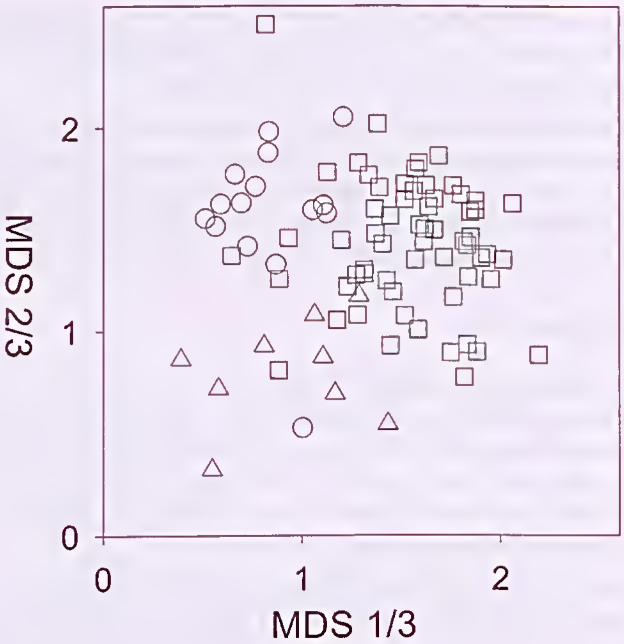

Fig. 7. First two axes of a three-dimensional ordination, including all sites. Squares represent the dryland sodic-scald sites, triangles the wetland sodic-scald sites, and circles the plots from other vegetation types in the surrounding landscape.

parviflorus (13 plots) and *Portulaca bicolor* (12 plots). Wetland plots within the sodic-scald are also floristically distinctive occupying a discrete portion of the ordination space. There were 18 species only recorded from the 10 plots that included some wetland within the sodic-scald area and the most frequent of these were *Leptochloa fusca* (9 plots), *Cyperus difformis* (6 plots), *Eleocharis pusilla* (5 plots), *Brachyscome basaltica* (4 plots) and *Goodenia gracilis* (4 plots).

Drainage line is also directly parallel and strongly related to the primary gradient within an ordination of the sodic-scald plots only. A secondary gradient almost orthogonal to the primary gradient is strongly related to pH (Fig. 8). The pH vector is roughly parallel with an increasing incidence of basement, and the direction of this vector is opposed to the vector relating to upper catchment sites.

The most frequent species in the 70 sodic-scald plots were *Tripogon loliiformis* (57 plots), *Sporobolus coromandelianus* (55 plots), *Fimbristylis dichotoma* (54 plots), *Sclerolaena tricuspis* (52 plots), *Portulaca oleracea* (49 plots) and *Atriplex leptocarpa* (46 plots). Together with other species they form short grassland on the Pedestal and Slope surface features. The scores of species along the two most significant vectors, drainage lines and pH were collated. The species with high drainage lines scores tend to be fairly rare representing the relative scarcity of wetland sites. *Fimbristylis dichotoma* has an association with low pH sites and *Sporobolus coromandelianus* and *Atriplex leptocarpa* with high pH sites (Appendix).

Table 1. Count intercepts (percentage cover) for the surface feature categories according to ground cover type for sites within the sodic-scald land type.

Landform	Plant	Cryptogam	Litter	Bare	Grand Total
Drainage line	56 (82.4)	2 (2.9)	1 (1.5)	9 (13.2)	68
Pedestal	26 (60.5)	9 (20.9)	0 (0.0)	8 (18.6)	43
Slope	143 (32.9)	149 (34.3)	24 (5.5)	119 (27.4)	435
Basement	9 (5.8)	14 (9.1)	0 (0.0)	131 (85.1)	154
Grand Total	**234 (33.9)**	**174 (25.2)**	**25 (2.8)**	**267 (38.1)**	**700**

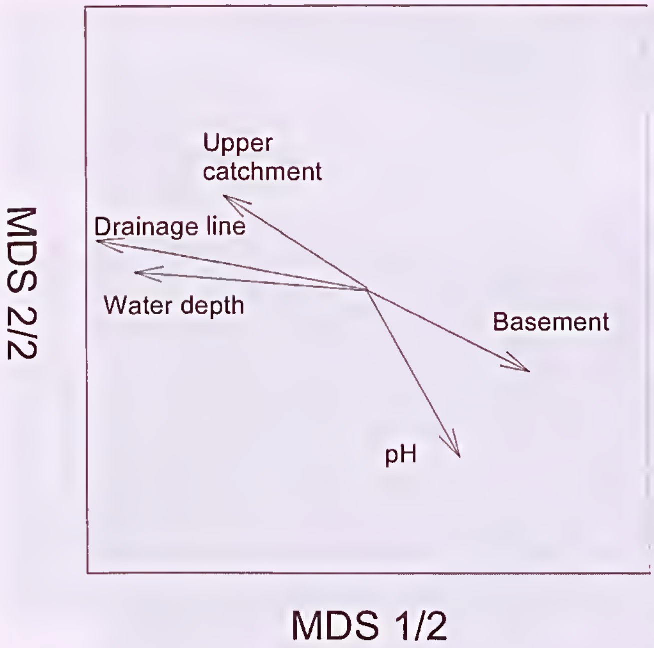

Fig. 8. Highly significant vectors ($P<0.001$) through the two-dimensional ordination solution for saline scald plots. Vectors for grazing index and cover of Slope and Pedestal microtopography categories are non-significant ($P>0.05$).

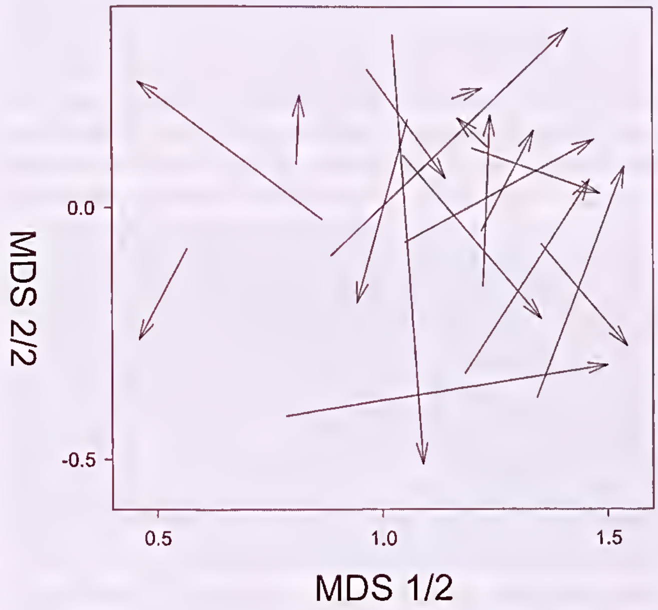

Fig. 9. Two-dimensional ordination of stock route-paddock paired plots. The arrows join stock route-paddock pairs with the tail on the position of the stock route and the head on the position of the paddock.

There were no significant differences (P>0.05) in frequency of surface feature categories between stock route and paddock. Plant cover was more frequent on the stock route than the paddocks (Median difference = 10%), although the significance was weak (Wilcoxon statistic = 26.5; N for test = 16; *P*-value = 0.034) and could be accounted for by multiple comparisons in the context of alpha error (Rice 1989). There was no significant difference between stock route and paddock for any other ground cover types, nor for soil penetration depth.

Of the 19 relatively frequent species in the stock route-paddock plot pairs, only *Portulaca pilosa* (Median difference in cover = 0.25%; Wilcoxon statistic = 5.5; N for test = 10; *P-value* = 0.028) and *Verbena aristigera* (Median difference in cover = 0.25%; Wilcoxon statistic = 0.0; N for test = 7; *P-value* = 0.022) were more abundant on the stock routes, although the weak significance of the results is inconclusive in the context of multiple comparisons. The small differences in floristics between ungrazed stock routes and paddocks are also demonstrated by their relative position within the ordination. Paddocks and stock routes for paired plots straddling fence-lines have no consistent relationship with ordination dimensions and may be neighbouring or widely separated (Fig. 9).

Discussion

The soils at the Yelarbon sodic-scald are extreme and the vegetation is clearly distinct from the surrounding landscape. *Brachyscome* sp. (RJ Fensham 5553) may be endemic to the sodic-scald and another suite of faithful species (*Angianthus brachypappus, Disphyma crassifolium, Lepidium monoplocoides, Maireana pentagona* and *Sarcozona praecox*) are at their northern limit at Yelarbon. The disproportionate number of succulent species in the sodic-scald area suggests that succulence is an adaptation to the extreme conditions, with the succulent family Aizoaceae well represented (Appendix). The most abundant of the indicator species for the sodic-scald were *Atriplex leptocarpa* and *Sporobolus coramandelianus*. These species are reasonably widespread and may represent useful indicators of high sodicity or salinity in other areas. Some species such as *Tripogon loliiformis, Fimbristylis dichotoma, Sclerolaena tricuspsis* and *Portulaca oleracea* are common on the sodic-scald and widespread in other environments.

There is some similarity between the vegetation descriptions from land resource assessment studies from areas in southern Queensland to the west of Yelarbon (Land unit 66, Galloway *et al.* 1974; Land Unit 35, Dawson *et al.* 1974; Land unit 8, 13, Mills *et al.* 1990). In the brief descriptions provided in these reports, the grasses *Dactyloteniunn radulans* and *Tripogon loliiformis*, and *Trianthema triquetra* are typical and are also common at Yelarbon (Appendix). The chenopod genera *Atriplex* and *Sclerolaena* are also a common feature of scalds, but not necessarily the same species that are common at Yelarbon. Reports from other areas to the south in New

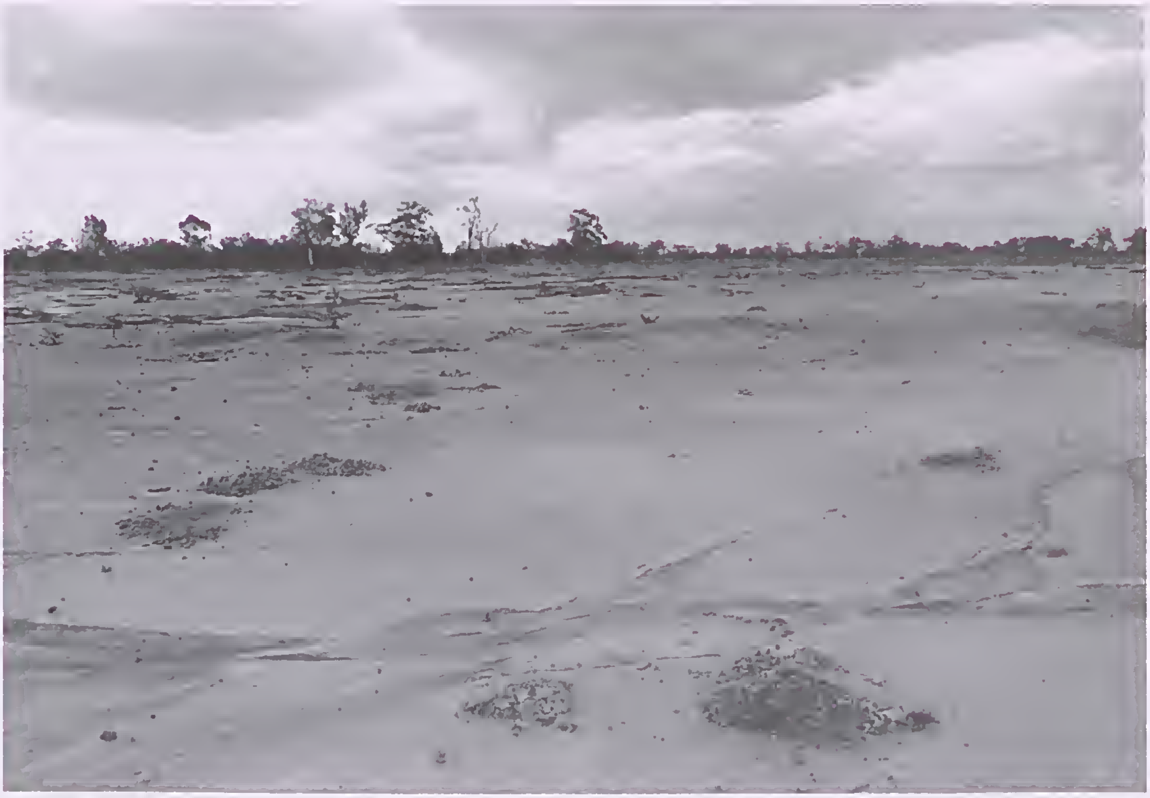

Fig. 10. Aboriginal hearth places have been exposed by erosion at Yelarbon and may yield important evidence relating to the landscape history and dynamism of the sodic-scald at Yelarbon.

South Wales come from locations that have been heavily altered by land clearing and pasture development, and are generally more temperate (i.e. Kreeb *et al.* 1995; Briggs and Taws 2003).

Drainage depressions forming ephemeral wetlands are a strong determinant of vegetation pattern, but the indicator species (Appendix) are generally widespread and also occur in wetlands of non-sodic landscapes.

Within the sodic-scald area, a primary floristic gradient is correlated with the pH of the surface soil (Appendix). This floristic gradient is represented at the high alkalinity end by species capable of growing on the extreme environment of the scalded sub-soils, and at the low alkalinity end by species associated with the leached residual A-horizons that have persisted in upper catchment areas. The most frequent of the non-wetland species at the high alkaline end of the pH vector are *Atriplex leptocarpa, Portulaca pilosa, Sporobolus coramandelianus* and *Trianthema triquetra*; with *Bryophyllum delagoense, Chloris ventricosa, Dactyloctenium radulans, Enteropogon acicularis, Fimbristylis dichotoma, Salsola kali* most frequent at the less alkaline end of this vector.

The sodic-scald at Yelarbon spans multiple levels of alluvia at the junction of two substantial streams, the Dumaresq River and MacIntyre Brook (Fig. 1). Lower areas are flooded from over-bank flow, while the highest areas experience overland flooding. Run-off during extreme flood events probably accounts for the majority of soil loss at Yelarbon, as is the case for other areas of western New South Wales (Fanning 1999). Local knowledge verifies that mass soil movement is mostly confined to extreme rainfall events that result in the flooding of the Dumaresq River or Macintyre Brook as occurred in 1956 and 1976. Run-off velocity and volume is highest in the lower reaches where major soil loss is evident as deep erosion gullies (Fig. 3). The study of McIvor *et al.* (1995) suggests that plant cover below 40% did not exacerbate soil movement during extreme events, while Eldridge and Rothon (1992) attributed weak relationships between soil movement and plant cover to the high porosity of the soil at their study site in New South Wales. It seems likely that surface soils at Yelarbon are highly vulnerable to sheet erosion given their dispersive character, the hard-pan formed by the sub-soil, a climate that can oscillate between drought and flooding rain in a short period, and the inherently unfavourable environment for plant growth.

Deposition also occurs in some areas during flood events. Aboriginal hearth-places have been buried by flood deposits and subsequently exposed by erosion (Fig. 10). Flood deposits support sparse vegetation dominated by perennial short grassland dominated by *Sporobolus coramandelianus, Tripogon loliiformis, Fimbristylis dichotoma, Sclerolaena tricuspis* and *Atriplex leptocarpa* short-grassland akin to that on the sodic-scald at large. Many areas of the Pedestal surface features may be remnants of old flood deposits.

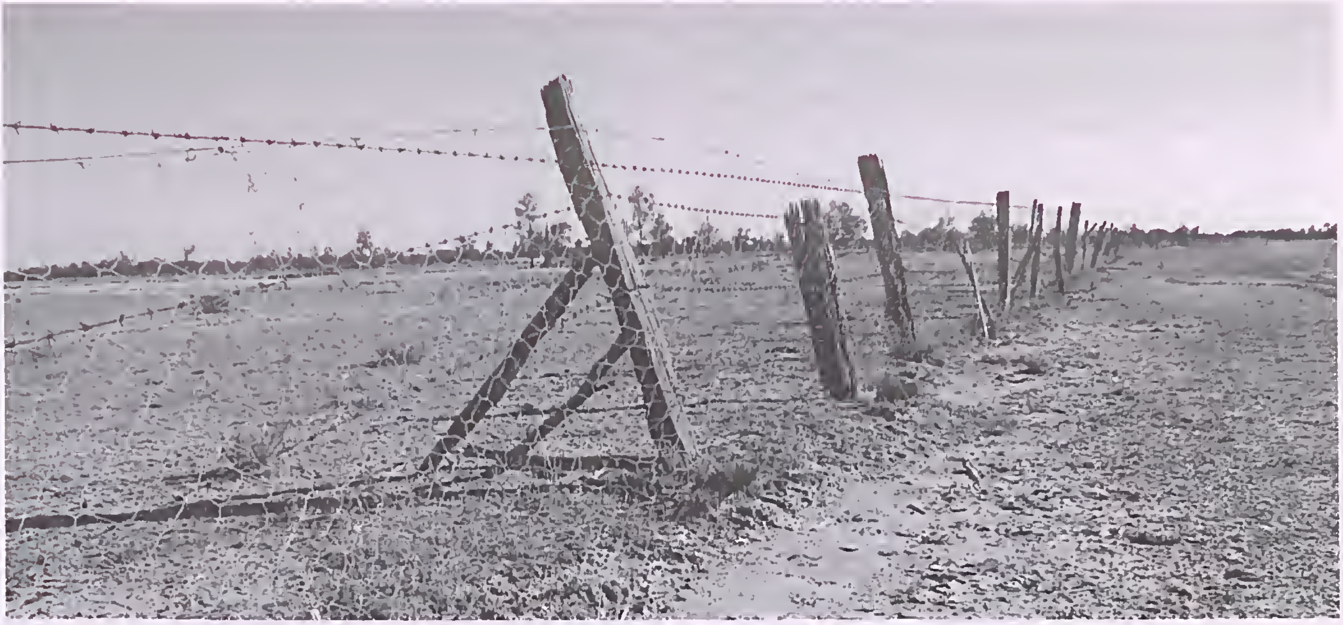

Fig. 11. Stripping of the A-horizon along the stock route (right)-paddock (left) fence at the Yelarbon sodic-scald. This is evident as the scalding on the eastern stock route on Fig. 4.

Surface soils of the Pedestal may also be formed by lateral drainage of water removing dispersed clays out of surface material. This means of profile development has been postulated for sodic soil-catenas in Africa (Dye and Walker 1980). Further study of the landscape processes that formed and maintain the extreme environment of the sodic-scald could provide important insights relevant to the management of the large areas of semi-arid Australia soils affected by primary and secondary (management-induced) scalding by sodicity and salinity. The aboriginal hearths contain charcoal, which could be dated to give some temporal perspective on landscape processes (Holdaway *et al.* 2002).

There was no obvious change in the pattern of scalded area between 1948 and 2003 (Fig. 4). A grazing effect on vegetation pattern, soil cover or surface feature patterns was not clear from the plot data although a residual signature of the historical grazing impact on the stock route remains evident on the recent aerial photography and in some places in the field (Fig. 11). Grazing gradients constructed across fence-lines have been demonstrated to have substantial effects on soil surface conditions including cryptogamic crust cover, plant litter, pH and infiltration (Graetz and Tongway 1986) and vegetation composition in other Australian environments (Fensham *et al.* 1999). It is possible that grazing use had a substantial impact prior to the establishment of the stock route fence in the early part of the twentieth century. In the early decades of settlement free ranging stock and plagues of rabbits may have denuded vegetation sufficiently to have accelerated erosion. However, the Yelarbon sodic-scald is a naturally active landscape regardless of grazing.

Acknowledgements

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Appendix 1

Vascular plant pecies list for the Yelarbon sodic-scald species only, and the frequency of their occurrence in the 70 plots. Nomenclature follows Bostock and Holland (2007). Species without frequency values were only found during the post-winter survey in October 2006. Exotic species are identified with an asterisk and succulent species with a hatch. Average scores (weighted by species cover) for the two most significant environmental correlates (see Fig. 8), pH and the Drainage line vectors are also provided. Drainage line scores represent the percentage of the transect that intersects with the drainage line microtopographic category. The vector scores are derived from the ordinal position of that species on the vector and relate directly to the range of scores for that variable. Thus the higher the score for pH the stronger the association with alkaline sites, and the higher the drainage vector score the stronger the association with sites with a high proportion of drainage surface feature (a surrogate for wetland habitat).

	Frequency	**pH vector score**	**Drainage line vector score**
PTERIDIOPHYTA			
Marsileaceae			
Marsilea hirsuta	9	7.48	6.94
Ophioglossaceae			
Ophioglossum lusitanicum	1	8.06	0
Sinopteridaceae			
Cheilanthes distans	18	7.98	0.83
Cheilanthes sieberi	7	7.63	2.29
ANGIOSPERMAE			
Acanthaceae			
Brunoniella australis	2	6.55	0.5
Rostellularia adscendens	2	7.49	0

Aizoaceae			
Calandrinia calyptrata#	2	7.86	0
Calandrinia pickeringi#	1	6.89	0
Calandrinia pumila#	1	7.43	0
Disphyma crassifolium#	1	8.44	0
Grahamia australiana#	5	7.24	1.67
Portulaca australis#	17	7.82	0.24
Portulaca bicolor#	12	7.59	0
Portulaca filifolia#	9	7.51	0.33
Portulaca oleracea#	49	7.76	0.25
Portulaca pilosa#	27	8.03	0.15
Sarcozona praecox#	17	7.94	0
Trianthema triquetra#	27	8.6	0.06
Amaranthaceae			
Alternantha angustifolius	6	8.09	4
Alternantha denticulata	8	7.47	4.75
*Gomphrena celosoides**	3	7.6	5
Nyssanthes erecta	1	7.5	10
Apiaceae			
Eryngium plantagineum	1	7.35	9
Asclepiadaceae			
*Gomphocarpus physocarpus**	1	8.1	0
Asteraceae			
Angianthus brachypappus	3	8.01	0
*Aster subulata**	3	8.6	1.33
Brachyscome basaltica	5	9.31	2.94
Brachyscome ciliaris	19	7.83	0.21
Brachyscome sp. (RJ Fensham 5553)	1	8.1	0
*Calendula arvensis**			
Calotis cuneifolia	2	7.43	0.5
Calotis hispidula			
Centipeda minima	2	7.6	3
Chrysocephalum apiculatum	1	8.1	0
*Conyza bonariensis**	2	7.49	0
Eclipta platyglossa	3	7.25	6.67
Epaltes australis	6	7.47	1.5
*Hypochaeris microcephala**	1	7.1	6
Lagenifera gracilis	2	7.19	5
Podolepis muelleri			
Soliva sessilis			
Triptilodiscus pygmaeus			
Vittadinia pustulata	21	7.92	0.62
Vittadinia sulcata	2	7.8	0
Boraginaceae			
*Heliotropium amplexicale**	5	7.59	2.2
Brassicaceae			
*Lepidium africanum**	8	7.67	1.25
Lepidium monoplocoides	6	7.85	0.33
Cactaceae			
Harrisia martini#	2	7.35	0
Optunia aurantia#*	14	7.54	0.21
Opuntia stricta#*	14	8.12	1.36
Opuntia tomentosa#*	3	7.51	3.33
Campanulaceae			
Wahlenbergia fluminalis	12	8.06	0.58
Wahlenbergia gracilis	3	7.63	5
Casuarinaceae			
Allocasuarina luehmannii	9	6.49	0.01
Chenopodiaceae			
Atriplex leptocarpa	46	8.08	0.09
Atriplex semibaccata	17	8.01	7.58
Chenopodium carinatum	1	7.3	0
Einadia nutans	5	7.07	0.2
Einadia polygonoides	2	7.24	0
Enchylaena tomentosa#	14	7.45	0.67
Maireana microphylla	1	6.89	0
Maireana pentagona	8	7.25	1.75
Rhagodia spinescens	6	7.1	2.5
Salsola kali	28	7.45	0.15
Sclerolaena bicornis	15	7.61	0
Sclerolaena birchii	5	7.35	2.2
Sclerolaena muricata	3	7.37	3
Sclerolaena tricuspis#	52	7.51	0.19
Tetragona tetragonioides#	1	7.5	10
Clusiaceae			
Hypericum gramineum	1	8.1	0
Commelinaceae			
Commelina cyanea	19	7.78	1.42
Murdannia graminea	4	8.43	9.76
Convolvulaceae			
Dichondra repens	1	7.5	10
Evolvulus alsinoides	3	6.92	0
Crassulaceae			
Bryophyllum delagoense#*	33	7.22	3.09
Crassula sieberiana			
Cupressaceae			
Callitris glaucophylla	1	8	0
Cyperaceae			
Bulbostylis barbata	3	7.43	0
Carex appressa	2	7.35	8.97
Carex inversa	3	7.3	7
Cyperus difformis	7	7.4	5.67
Cyperus gracilis	3	6.72	0
Cyperus rigidellus	6	6.93	8.2
Eleocharis blakeana	1	6.8	9
Eleocharis plana	4	8.03	0.47
Eleocharis pusilla	5	8.37	9.62
Fimbristylis dichotoma	54	7.45	3.59
Euphorbiaceae			
Chamaesyce drummondii	8	7.43	2.5
Phyllanthus virgatus	3	7.66	0
Fabaceae			
Glycine clandestina	3	7.5	3.33
Medicago minima			
Goodeniaceae			
Goodenia gracilis	4	7.73	6.5
Haloragaceae			
Haloragis heterophylla	1	8.1	0
Myriophyllum gracile	1	7.2	3
Hypoxidaceae			
Hypoxis hygrometrica	1	8.1	0
Juncaceae			
Juncus subsecundus	5	7.35	8.5
Lamiaceae			
Plectranthus parviflorus#	13	7.53	2
Liliaceae			
Bulbine semialata	3	8.04	0
Crinum flaccidum	1	7.1	6
Malvaceae			
Abutilon oxycarpum	4	7.08	2.75

*Sida rhombifolia**	1	10	2
Sida trichopoda	7	7.2	3.33
Menyanthaceae			
Nymphoides crenata	2	7.28	5.13
Myoporaceae			
Eremophila deserti	3	7.74	0
Eremophila longifolia	1	8	0
Eremophila debile	3	7.2	3.33
Myrtaceae			
Melaleuca densispicata	9	7.28	4.26
Nyctaginaceae			
Boerhavia repleta	6	7.12	1.67
Oleaceae			
Notelaea microcarpa	2	7	5
Oxalidaceae			
Oxalis chnoodes	4	7.45	3.75
Oxalis perennans	2	7.45	3.75
Phormiaceae			
Dianella longifolia	2	8.11	0
Pittosporaceae			
Pittosporum angustifolium	1	6.8	3
Plantaginaceae			
Plantago turrifera			
Poaceae			
Aristida jerichoensis	2	6.85	0
Aristida leichhardtiana	1	6.35	0
Aristida longicollis	2	7.5	5
Aristida ramosa	2	8.89	0.5
Austrodanthonia linkii	2	6.93	5
Austrostipa scabra	4	7.45	2.5
Bothriochloa decipiens	13	7.76	2.14
*Cenchrus ciliaris**	2	7.4	5
Chloris divaricata	1	8.1	0
*Chloris gayana**	1	8.3	0
Chloris truncata	17	7.87	1.61
Chloris ventricosa	18	7.49	3.49
Cymbopogon refractus	7	7.51	2.14
*Cynodon dactylon**	6	8.28	0.24
Dactyloctenium radulans	21	6.93	8.2
Dichanthium sericeum	3	7.8	3.67
Digitaria brownii	2	7.7	0
Digitaria diffusa	3	7.5	3.33
Digitaria divaricatissima	2	7.78	5
*Echinochloa colona**	1	7.1	6
Enneapogon gracilis	12	7.89	0.48
Enteropogon acicularis	19	7.25	0.23
Eragrostis alveiformis	6	7.95	0.17
*Eragrostis curvula**	1	8.44	0
Eragrostis elongata	3	8.47	1.67
Eragrostis lacunaria	9	7.21	0.1
Eragrostis leptostachya	4	7.21	2.5
Eragrostis parviflora	15	7.86	3.76
Eragrostis sororia	9	7.58	1.13
Eriochloa pseudoacrotricha	23	7.5	7.18
Eulalia aurea	1	7.3	5
Leptochloa decipens	6	6.99	0.65
Leptochloa digitata	1	7.3	5
Leptochloa divaricatissima	1	6.35	0
Leptochloa fusca	10	7.58	7.71
Oxychloris scariosa	2	7.86	0
Panicum buncei	11	7.95	2.18
Panicum effusum	1	8.1	0
Paspalidium caespitosum	3	7.11	0
Paspalidium constrictum	4	7.36	0.25
Paspalidium distans	5	7.32	1.6
Paspalidum gracile	1	8	0
*Paspalum dilatatum**	2	7.52	3.67
Paspalum distichum	2	7.35	9.03
Poa fordeana			
*Melinis repens**	1	7.32	0
Setaria parviflora	1	10	2
Sporobolus caroli	1	8.33	2
Sporobolus coramandelianus	55	8.04	0.21
Sporobolus creber	3	7.15	0
Tragus australiensis	29	7.94	0.41
Triodia scariosa	16	7.8	0.16
Tripogon lolliformis	57	7.6	0.19
Vulpia muralis			
Walwhalleya subxerophila	1	7.1	6
Rubiaceae			
Oldenlandia trachymenoides	1	8.1	0
Psydrax oleifolia	2	7.8	5
Rutaceae			
Geijera parviflora	3	7.5	3.33
Santalaceae			
Santalum lanceolatum	3	7.87	3.33
Scrophulariaceae			
Glossostigma diandrum	2	7.35	7
Peplidium foecundum	1	8.5	10
Solanaceae			
Solanum ferrocissimum	2	6.99	3.33
Thymelaeaceae			
Pimelea neo-anglica	2	6.8	3
Verbenaceae			
*Verbena aristigera**	22	7.95	0.64
Xanthorrhoeaceae			
Lomandra multiflora	1	8.1	0
Zygophyllaceae			
Tribulus terrestris	2	7.97	5

Pre-clearing vegetation of the coastal lowlands of the Wet Tropics Bioregion, North Queensland

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***Abstract*:** A pre-clearing vegetation map and digital coverage at approximately 1:50 000 scale for the coastal lowlands (up to about 200 m elevation) of the Wet Tropics Bioregion, North Queensland is presented. The study area covers about 508 000 ha from Cooktown, 420 km south almost to Townsville (latitude 15° 30'–18° 20' longitude 144° 50'–146° 40'). Data sources included historical aerial photography, early surveyors' plans, explorers' journals, previous vegetation maps, and maps of soils and geology. The pre-clearing mapping was built around the remnant vegetation mapping of Stanton & Stanton (2005), and the vegetation classification of this latter work was adopted. Vegetation units were further classified into regional ecosystems compatible with the standard State-wide system used by Queensland government. The digital coverage is part of the current Queensland Herbarium regional ecosystem coverage (Queensland Herbarium and Wet Tropics Management Authority 2005). Coloured maps (1:100 000 scale) of the pre-clearing vegetation of the Herbert, Tully, Innisfail and Macalister/Daintree subregions are on an accompanying CD-ROM.

An evaluation of vegetation loss through clearing on the coastal lowlands of the Wet Tropics revealed several near-extinct vegetation communities and regional ecosystems, and many others that are drastically reduced in area. Even ecosystems occurring on poorly drained lands have suffered a surprisingly high level of loss due to the effectiveness of drainage operations. Grassland ecosystems were found to be widespread on the Herbert and Tully floodplains, but are now close to extinction. The lowlands vegetation of the Wet Tropics that remains today continues to be fragmented and degraded despite the introduction of State-wide broad-scale tree-clearing laws in 1999, and the cessation of broad-scale tree-clearing in December 2006.

***Cunninghamia* 10(2): 285–329**

Introduction

Much of Australia has been cleared of native vegetation for agricultural and urban development since European settlement began in the 19th century, a relatively short time. The extent of clearing for each State is now estimated at 60% of Victoria, 30% of New South Wales, 18% of Queensland, 16% of Tasmania, 11% of South Australia, 7% of Western Australia, and 2% of the Northern Territory (National Land & Water Resources Audit 2001). In Queensland, most of the clearing has taken place in the 20th century, allowing reconstruction of the nature of the pre-clearing vegetation using a variety of documentation and aerial photography. The Wet Tropics Bioregion, in north-eastern Queensland has good aerial photo coverage, with the earliest taken in the 1940s (as early as 1937 in the Cairns city area) by the Royal Australian Air Force (R.A.A.F.), for military purposes. There are also detailed land survey plans drawn up in the 19th and early 20th centuries for all new land allocated for settlement. These plans often show major vegetation boundaries. Most of this land survey information is available today from the Queensland Department of Natural Resources and Water.

Indigenous people have lived in the Wet Tropics for many thousands of years. Radio-carbon data from Ngarrabullgan Cave at Mt Mulligan, 50 km west of the Wet Tropics, suggests this area was inhabited 35 000 years ago (Lorandos & David 2002). In the late 19th century, at the time of European settlement, the wet tropics supported at least 60 clan groups, and at least eight major language groups (Bottoms 2000). The rainforest clans had high population densities (Horsfall 1987), with large semi-permanent camps (Dalrymple 1873, Mulligan 1876, Birtles 1982, Anderson 1984). Permanent walking tracks were common and apparently impressive (*a broad hard-beaten path* (Dalrymple 1865); *splendid native tracks* (Mulligan 1876); *many large paths* (Palmerston 1885–1886); *the largest native path I have seen* (Palmerston 1887)), with major tracks connecting upland and lowland resources (Palmerston 1887, Bottoms 2000). Open areas in rainforest and sclerophyll forest, which were carefully maintained and kept open (and in many cases cleared from the forest), served as campsites and/or ceremonial areas (Palmerston 1885–1886, Palmerston 1887, Lumholtz 1889, Mjöberg 1918, Birtles 1982). The practice of regular burning, for reasons including driving (or attracting) game, improving ease of travel, and for ridding of pests such as leeches, was common (Lumholtz 1889, Tindale 1976, Anderson 1984, Bottoms 2000). Some authors caution that in the Mossman District, the use of fire may have become more common in early European contact days as a tool in frontier conflict, though they also concede it had previously been used to manipulate vegetation (Hill *et al.* 2000). Certain plant resources were maintained by encouraging regeneration after harvest (Bottoms 2000). From the evidence available it is clear that indigenous people were likely to have had substantial influence on the nature of vegetation communities, and the associated fauna.

From the 1840s Europeans were fishing and cutting timber from the Wet Tropics (Bottoms 2000), and from about 1870, small areas of land were taken up for sugarcane plantations, first near Cardwell, and then on the Herbert River delta (Frawley 1983, 2000). The area under sugarcane rapidly expanded during the 1880s; by this time, most of the useful Red Cedar timber, *Toona ciliata*, had been harvested from the lowlands (Frawley 1983, 2000). With support of a South Sea Islander workforce, agricultural expansion accelerated again in the 1890s and early 1900s. A state land development policy in the first decade of the 20th century saw large areas surveyed for cattle farming, and between Tully and Cooktown, large areas were subdivided and cleared in the 1920s (Frawley, 1983, 2000).

In the 1950s there was some realisation that formerly plentiful resources were becoming scarce, but agricultural and pastoral development continued. In 1963 for example, the pastoral property King Ranch (21 000 ha in the Tully River Valley) was salvage-logged by the Forestry Department, and then cleared (Frawley 2000). Small areas of land continued to be cleared. In the late 1980s and early 1990s large areas of lowlands vegetation were clear-felled on State lands for the establishment of pine plantations, particularly in the Cardwell area and the Herbert floodplain (Abergowrie, Broadwater and Lannercost State Forests). At about this time (1989) a rare marsupial, the Mahogany Glider, *Petaurus gracilis*, previously not recorded since its original description in 1883, was re-discovered, clinging to the remnants of habitat confined to the Herbert and Tully lowlands, and critically endangered by clearing (Van Dyck 1993). A subsequent development rush was triggered, amid fears of impending clearing restrictions, and a large proportion of the remaining arable land in the Herbert and Tully lowlands (within the range of the Mahogany Glider) was cleared of timber.

Shortly before the introduction of State tree clearing laws in 2000 (Vegetation Management Act 1999), another minor clearing surge was initiated, but by this time most of the available land had been cleared, with the remainder either within reserves, or too swampy or saline to clear. The remnant native vegetation on the floodplain of the wet tropics is today (except for estuarine areas) severely depleted, with many of the remnants existing in various stages of weed invasion and structural alteration due to cessation of burning, timber harvesting and other activities.

This paper presents pre-clearing maps of the cleared areas of the coastal lowlands of the Wet Tropics, with vegetation patterns reconstructed following standard criteria for pre-clearing regional ecosystems coverage elsewhere in Queensland (Neldner *et al.* 2005). No previous project has attempted pre-clearing mapping of such a large proportion of the Wet Tropics at such a detailed vegetation community level. A second paper presenting pre-clearing mapping of the (higher elevation) Atherton tablelands of the Wet Tropics, is planned. These two areas, combined with the remnant vegetation and regional ecosystem mapping adapted from Stanton and Stanton (2005), form a bioregion-wide pre-clearing vegetation coverage of the Wet Tropics. This full coverage exists as a joint Wet Tropics Management Authority (WTMA) and Queensland Herbarium product (Queensland Herbarium & Wet Tropics Management Authority 2005), and is currently used by the Queensland Department of Natural Resources and Water (DNRW) for the administration of Queensland vegetation management legislation.

Methods

The coastal lowlands of the Wet Tropics study area

The study area covers the coastal lowlands area (508 044 ha) of the Wet Tropics bioregion, north-eastern Queensland (Goosem *et al.* 1999; Environmental Protection Agency 2003a), and extends from near Cooktown south 420 km, almost to Townsville (latitude 15° 30' to 18° 20' longitude 144° 50' to 146° 40') (Figure 1). Altitude ranges from sea level along the coast to approximately 200 m where the lowlands meet low foothills, or end abruptly at the bottom of steep mountainous terrain. Annual rainfall varies from approximately 1200 mm near Bluewater (at the southern end of the study area) to 4200 mm at Babinda (in the centre). The area has a tropical climate, and the natural vegetation includes eucalypt open forests, tea tree woodlands, dense tea tree swamps, sedgelands, grasslands and rainforest. Most of the original rainforest was confined to the fertile river and creek levees, with the exception of the highest rainfall areas where rainforest covered entire valleys. Approximately 10% of the study area today lies within the Wet Tropics World Heritage Area.

The Wet Tropics coastal lowlands are mainly within three subregions: Herbert (Herbert River valley), Tully (Tully and Murray River valleys) and Innisfail (valleys of the Barron, Mulgrave, Russell and Johnstone rivers, and Liverpool Creek), with minor areas in the Daintree-Bloomfield (Bloomfield, Daintree, Mossman River valleys and associated ranges and tablelands) and Macalister subregions (Macalister Range) (Goosem *et al.* 1999). Only minor pre-clearing areas were mapped in the Macalister subregion (these are included within the analysis and discussion of the Daintree-Bloomfield subregion).

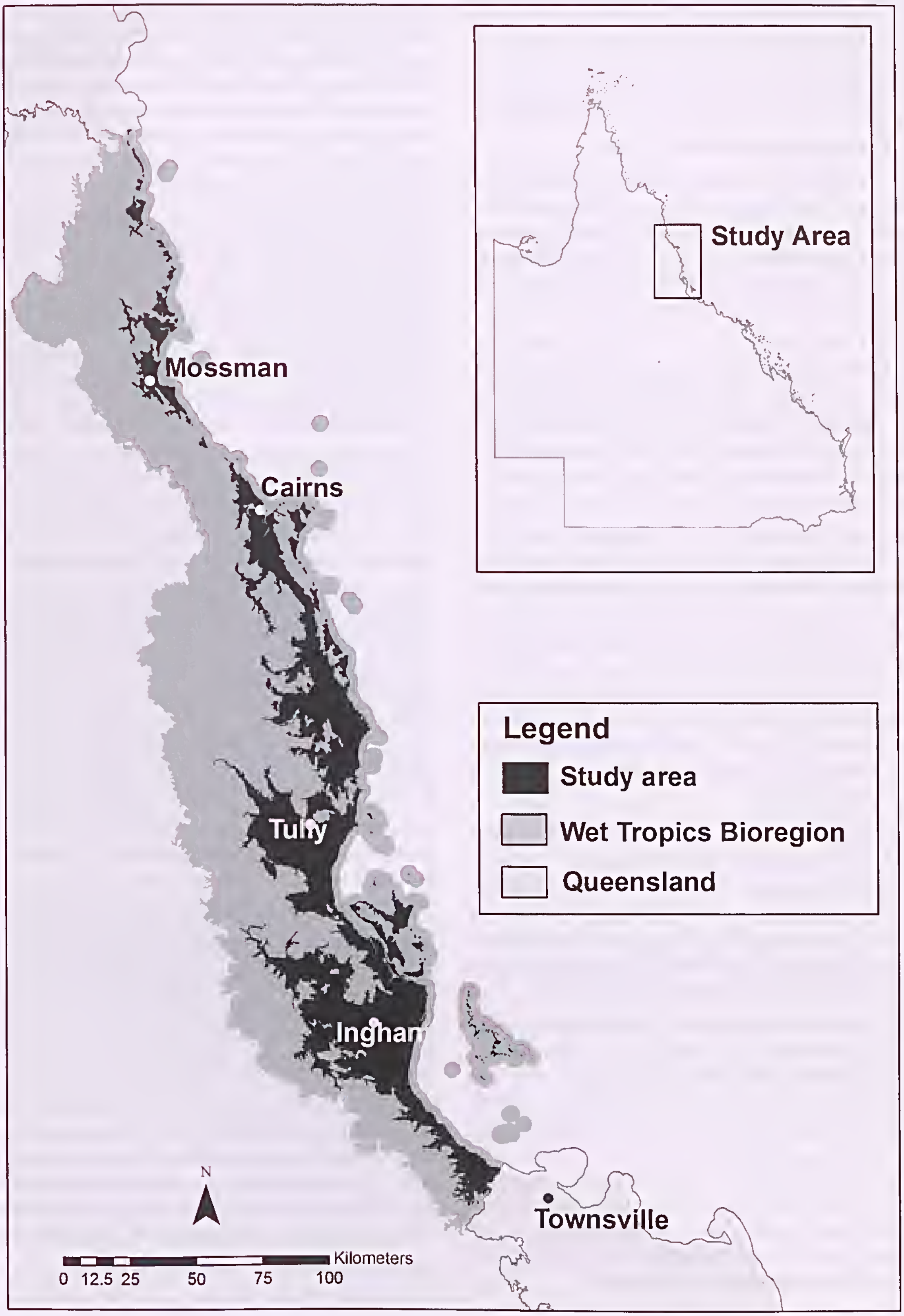

Fig. 1. The coastal lowlands of the Wet Tropics study area.

The Herbert is the driest subregion (annual rainfall 1200–2200 mm), with a very broad, alluvial plain, with fertile river levees and prior streams, and extensive poorly-drained plains. The vegetation consists of woodlands of *Eucalyptus platyphylla* and *Melaleuca viridiflora*, open forests and dense stands of *Melaleuca quinquenervia*, *Corymbia tessellaris* and *Eucalyptus tereticornis*, rainforests (along the Herbert River levee) and extensive mangrove systems.

The Tully subregion has a higher rainfall (annual rainfall 2200–3800 mm) and supports swampy *Eucalyptus* and *Melaleuca* forests, *Eucalyptus tereticornis* forests, grasslands, and rainforest (particularly in the upper Tully Valley, and along the Tully and Murray levees). It contains extensive coastal dune systems, including large areas of older dunes of Pleistocene age.

The Innisfail subregion has a similar, to slightly higher rainfall (annual rainfall 2000–4200 mm) than the Tully subregion, and has a greater area of well-drained, fertile soil (with large areas of basalt), supporting rainforest, or in swampier areas, palm swamps. Extensive dune systems and paperbark swamps are also a feature.

The near-coastal lowlands of the Daintree Bloomfield subregion are moderately wet (annual rainfall 1900–3500 mm) and fertile, and the alluvial plains are small and narrow, and usually backed by steep mountain ranges. Rainforest is common, and where swampy is often dominated by fan palms. *Eucalyptus* forests tend to be dense and dominated by species such as *Eucalyptus pellita*, *Eucalyptus leptophleba*, and *Eucalyptus tereticornis*, whilst drier, more northern areas, are dominated by more open forests of *Eucalyptus nesophila*. Swampy areas often support dense stands of *Melaleuca quinquenervia*.

The boundaries of the subregions in this study differ slightly from the current Queensland Herbarium subregional boundaries (Environmental Protection Agency 2003a) as boundaries were adjusted to match polygon boundaries of the new Wet Tropics mapping (Queensland Herbarium & Wet Tropics Management Authority 2005). Isolated hills in the floodplain were included if below 220 m altitude.

Within the subregional boundaries described above, the coverage of Queensland Herbarium and Wet Tropics Management Authority (2005) was used for area calculations in this paper. This coverage consists of original pre-clearing mapping produced by the authors, joined to the remnant vegetation mapping of Stanton and Stanton (2005). The colour map series on CDROM accompanying this paper (Maps 1 to 4) were generated to show only major areas of original pre-clearing work (the relatively intact (i.e. not cleared today) section from Rollingstone to Bluewater, for example, is not included on the colour maps).

Previous pre-clearing studies of the Wet Tropics Bioregion

Previous work describing or mapping pre-clearing vegetation in the Wet Tropics bioregion include pre-European mapping done by CSIRO for the Herbert River Valley (Johnson *et al.* 2000; Johnson & Murray 1997). Johnson *et al.* (2000) used a series of different aged aerial photos including the oldest aerial photos available, to map structural vegetation types, though it was limited to a small number of vegetation classes (8 natural vegetation patterns).

Accad (2003) showed that vegetation distribution in the Wet Tropics (including prediction over cleared areas) can be modelled by integrating a data model, a statistical model, and an ecological model using sophisticated GIS techniques and rule-based systems. Accad presented a pre-clearing vegetation map for the Innisfail lowlands, at a scale of approximately 1:50 000 to 1:70 000 (scale estimated by Accad (2003)) using a pre-release version of the Stanton and Stanton (2005) remnant vegetation coverage, with vegetation types grouped into twenty Tracey (1975) floristic associations. The results of this work present a more rapid, and less subjective alternative to traditional methods, as that used in this study, and may in the future be used as an alternative or in combination with these methods.

Hilbert and Ostendorf (2001) modelled vegetation using artificial neural networks, which use climate variables, terrain variables and soil classes, to predict relative suitability of environments for particular forest types. The models used simple structural types (rainforest versus sclerophyll) and attempted to predict up to 15 forest classes. As a tool to predict pre-clearing vegetation, this method was found to be 88% accurate on the Atherton Tablelands (accuracy determined by comparison with existing vegetation remnants), though predictions for the coastal lowlands proved much less accurate, due to the poorer resolution of soil parent material data for this area.

To estimate the pre-clearing extent of land types in the Herbert and Tully subregions, Kemp and Morgan (1999) and Kemp *et al.* (1999) created remnant land type mapping, and extrapolated this using soils and land-system coverages. This work provided useful rapid estimates, but was limited to the Herbert and Tully subregions, and is not as accurate as detailed mapping work from historical aerial photography.

Hill *et al.* (2000) created an 1890 vegetation map of the Mossman District using surveyor's plans, resulting in a map of four major vegetation classes. This work was a part of a project designed to establish whether fire regimes in the wet tropics have been responsible for rainforest decline, in the context of changes brought about by European occupation.

Vegetation classification and scale

The classification and scale used for the project was strongly influenced by the current-day Wet Tropics Bioregion vegetation mapping of Stanton and Stanton (2005). This coverage, adapted by the Queensland Herbarium to include regional ecosystems (Queensland Herbarium & Wet Tropics Management Authority 2005), formed a framework for the pre-clearing mapping. Pre-clearing interpretation commenced at the boundaries of this current-day mapping, and proceeded outwards into cleared areas; the same vegetation units were adopted to ensure a seamless coverage. The Queensland Herbarium & Wet Tropics Management Authority (2005) "pre-clearing" coverage of the Wet Tropics Bioregion is therefore a combination of current vegetation and pre-clearing vegetation. This closely approximates a true pre-clearing map except where there have been dramatic changes in vegetation structure since the middle of the century (e.g. tracts of vegetation undergoing rainforest invasion).

The Stanton and Stanton (2005) units were defined by distinct aerial photo-patterns, which represent a unique combination of canopy dominance and structure, and sometimes, distinct landforms. Each vegetation polygon was assigned a prefix code which represents one of 14 geological classes (Stanton & Stanton 2005). The combination of this prefix class and the vegetation code provided a unit which reflects a combination of vegetation and geology, and which is a suitable building block for construction of regional ecosystems (Goosem *et al*., 1999). To create a regional ecosystem coverage (Queensland Herbarium & Wet Tropics Management Authority 2005), each of the geological/vegetation combinations were assembled into related groups and assigned regional ecosystems according to the Queensland Herbarium's current criteria (Neldner et al. 2005).

In order to simplify some components of the analysis and discussion, and for comparison with other pre-European vegetation mapping projects, regional ecosystems were further grouped into broader vegetation groups for this paper. These groups are based on dominant taxa and landform, and differ slightly to the Broad Vegetation Groups used by Queensland Herbarium & Wet Tropics Management Authority (2005). For non-rainforest vegetation, the vegetation community and regional ecosystem descriptions utilise the structural classes from Neldner (1984), which are based on Specht (1970) (refer also to Neldner *et al*., 2005). Rainforest is classified and described using Webb's classification. (Webb 1978, Tracey 1982). Plant scientific names follow Bostock and Holland (2007). Common names are listed in Table 1, and were chosen from local texts, or from those commonly used by botanists and landowners in the area.

The approximate scale of the Stanton & Stanton (2005) remnant vegetation mapping was 1:25 000. Though we attempted to map at a similar scale, for some areas we only had 1:80 000 aerial photos; therefore less detail is shown in these areas. Overall the average scale of the pre-clearing work is approximately 1:50 000.

Table 1. List of plant scientific and common names.

Names are from local texts, or are those commonly used in the area.

Scientific name	Common name
Acacia celsa	brown salwood
Acacia crassicarpa	beach wattle
Acacia mangium	black wattle
Allocasuarina spp.	sheoaks
Allocasuarina littoralis	black sheoak
Annona glabra	pond apple
Archontophoenix alexandrae	feather palm
Chrysopogon aciculatus	Mackie's pest
Corymbia clarksoniana	Clarkson's bloodwood
Corymbia intermedia	pink bloodwood
Corymbia tessellaris	Moreton Bay ash
Corymbia torelliana	cadaghi
Cynodon dactylon	couch
Eucalyptus cloeziana	Gympie messmate
Eucalyptus drepanophylla	ironbark
Eucalyptus leptophleba	Molloy red box
Eucalyptus nesophila	Melville Island bloodwood
Eucalyptus pellita	red mahogany
Eucalyptus platyphylla	poplar gum
Eucalyptus portuensis	white mahogany
Eucalyptus tereticornis	forest red gum
Heteropogon triticeus	giant spear grass
Imperata cylindrica	blady grass
Licuala ramsayi	fan palm
Lophostemon suaveolens	swamp mahogany
Melaleuca dealbata	cloudy tea-tree
Melaleuca leucadendra	weeping paperbark
Melaleuca viridiflora	broad leaf tea-tree
Melaleuca quinquenervia	swamp paperbark
Mimosa pudica	sensitive weed
Mnesithea rottboelloides	northern canegrass
Myrmecodia beccarii	ant plant
Schoenoplectus litoralis	bulrush
Sorghum nitidum	brown Sorghum
Sorghum spp.	native Sorghum
Sporobolus virginicus	saltwater couch
Syncarpia glomulifera	turpentine
Toona ciliata	red cedar
Urochloa mutica	para grass

Mapping process

The pre-clearing mapping was based on a number of key sources of varying detail, mostly in digital coverage form, and displayed as layers in the Arcview 3 GIS application. Colour 1:25 000 scale aerial photos (from years 1992 to 2002) were rectified and stitched together to create a mosaic, which formed the mapping base (done by the Wet Tropics Management Authority with some assistance from the Queensland Herbarium). This mosaic was, for the majority of the study area, registered to the 1:50 000 geodata drainage layer. Towards the end of the project, Landsat satellite imagery produced by the Queensland Department of Natural Resources for their Statewide Landcover and Trees Study (SLATS) project, was considered to be a more accurately registered base, and therefore the remaining study area was aligned to this. Future releases of the coverage will involve a progressive updating of the remaining area to match this satellite imagery.

Black and white aerial photos showing pre-clearing natural vegetation were considered the most reliable depiction of pre-clearing vegetation and were used stereoscopically for direct vegetation interpretation wherever possible. The earliest aerial photos that provide full coverage of the Wet Tropics are the 1960–61 1:80 000 scale series; these were used for areas that appeared to be uncleared at that time (such as the lower Herbert subregion). For those areas already cleared on 1960–61 series, older photographs were used. Aerial photos used included 1937 1:7000 scale photos from the Cairns city area, and 1943 1:23 000 for the Herbert floodplain (Table 2, Appendix 1).

Although a range of different aged aerial photos were often used for a given area, a record of the oldest photos used was kept, so that further discoveries of older aerial photographs can be used for map updates. Line-work on recent colour aerial photography used for the adjacent remnant vegetation (Stanton & Stanton 2005) was frequently consulted to ensure consistency of photo-pattern interpretation between the two projects.

Whilst the older series (limited area) photographs were viewed stereoscopically for identification of patterns, the line-work itself was drawn on 1960–61, 1:80 000 series (using overlays). In some areas (e.g. Cairns city) line-work was first drawn on the older series photographs (1937, 1:7000 scale) and then transferred by eye to the 1960–61, 1:80 000 series. Every effort was made to retain the detail of the finer scale photos. All overlays have been kept by the Queensland Herbarium.

Vegetation patterns for areas already shown as cleared on the oldest aerial photos were re-constructed using other sources including original surveyors' plans (e.g. Figure 6) (archived

Table 2. Pre-1970s aerial photos utilised (refer also to Appendix 1).

Mapsheet (1:100 000)	Set name	Scale	Year	Runs
Ingham Cardwell, Kirrama, Kangaroo Hills	Ingham Program Aerial Photography	1:80 000	1961	1-10
Ingham, Kangaroo Hills	Ingham RAAF	1:23 000	1943	1-11, west key, east key
Ingham	Ingham Tri-met (Ingham to Townsville Vertical (Eastman Topographic safety), Cairns to Townsville	1:44 000	1942	etot 1_165v-262v
Kirrama	Mt Graham 43 Project Aerial photography	1:34 000	1943	5-6
Kangaroo Hills	Oak Hills 43 Program Aerial photography	1:25 000	1943	1-10
Tully, Innisfail, Cooper Point, Bartle Frere	Innisfail Program Aerial Photography	1:80 000	1961	1-10
Tully	R.A.A.F. Tully Area "A"	1:15 000	1937	1-13
Tully	R.A.A.F. Tully Area "C"	1:15 000	1937	1
Tully	Clump Point-Tully 51 Program Aerial Photography	1:24 000	1951	8
Innisfail	Palmerston-Innisfail 43 Program Aerial Photography (K. D. 817 & 819)	1:24 000	1943	1-10
Cooper Point, Bartle Frere	Cairns - Innisfail Transmission Line	1:23 000	1949	3-6
Bartle Frere	Bartle Frere 43 Program Aerial Photography	1:23 000	1943	1-10
Bartle Frere, Cairns	8th Photo Sqdn; U.S.A.A.F. Macalister Range, Cairns, Gordonvale	1:40 000	1942	A - G
Bartle Frere, Cairns	Cairns City 37 Project Aerial Photography	1:7 000	1937	1-8
Tully, Innisfail	Palmerston-Innisfail 43 Program Aerial Photography	1:24 000	1943	1-10
Cairns, Rumula, Mossman	Mossman-Cairns Program aerial photography	1:80 000	1960	2-7
Mossman	Mossman Area	1:24 500	1944	E-Tie, Q 6-10
Rumula	Rumula-Macalister	1:11 000	1969	Coast Tie

by the Department of Natural Resources & Mines). Appendix 2 shows the area for which surveyors' plans were used.

Fensham (1989) pioneered the use of historical records for detailed information on the nature of early-European vegetation, and created maps with complex vegetation boundaries largely sourced from historical surveyors' plans (Fensham & Fairfax 1997). The use of this historical resource is now standard Queensland Herbarium practice (Neldner et al. 2005). For this work we also created a digital representation of the plans to view with other layers in Arcview 3.

Identification of pre-clearing vegetation also required interpretation of landform patterns on cleared parts of aerial photos, using a stereoscope. We also used field knowledge of the ecological requirements of each vegetation unit as well as evidence from any surrounding remnant patches (both from field inspection, and from Stanton & Stanton 2005) to assist with this process. Field checking involved two short field trips, mainly aimed at examining very small remnant stands of trees, to assist with type allocation in areas with minimal information.

Soil coverage patterns (Murtha 1986, Murtha 1989, Wilson & Baker, 1990, Canon *et al.* 1992, Murtha et al. 1996) assisted classification and location of some vegetation types - particularly those now close to extinction. Soil boundaries were generally re-interpreted using stereoscopic aerial photo interpretation. Quaternary geological mapping (Holmes *et al.* 1991) was particularly useful for locating obscure Pleistocene-age dune systems (as were the soils coverages), and some of the more recent geology coverage (from Department of Natural Resources & Water) was also useful. Previous vegetation maps for particular areas (eg. Tait 1994) were also consulted since they often included vegetation that is now cleared. Internal reports on file at the Environmental Protection Agency, Townsville (Cumming 1992a, 1992b, 1993, 1995a, 1995b, and Kemp 1996) and Department of Primary Industries, Mareeba (Perry 1995) were also consulted for the same purpose. Vegetation site data collected by the Queensland Herbarium and EPA, Townsville was also used - particularly for those areas that have subsequently been cleared. The majority of this vegetation data is held in the Queensland Herbarium's CORVEG database (Queensland Herbarium, Brisbane).

The aerial photos (along with their pre-clearing line-work on overlays) were scanned and registered to the Wet Tropics Management Authority aerial photo mosaic (described previously) using either ArcGIS 8 or ERDAS Imagine 8. The line-work was then digitised by tracing the pre-clear lines in Arcview 3 or ArcGIS 8 (depending on the user), creating shapefiles. While digitising the pre-clear lines it was necessary to take care that the linework aligned with features on the aerial photograph mosaic. The vegetation community for each polygon was entered into point shapefiles. Conversion to polygon coverages and any final cleaning and editing was carried out in ArcInfo Workstation 8.

Several checks of the coverage were carried out by colouring the coverage (on screen) in a logical manner (eg. colours reminiscent of the shading of the photo-patterns) enabling rapid identification of geological or vegetation labelling errors. Visual comparisons were made with previous vegetation, soils and geological coverages. A comparison of the resulting coverage of pre-clearing vegetation communities with the soils coverages was made to assist with explanations on the distribution of some of the vegetation communities. The soils coverages were intersected with pre-clearing vegetation coverage to provide statistics of area of each soil type by vegetation community.

In addition, each vegetation community was displayed individually on screen, in order to check polygons in unexpected locations or habitats. Finally the coverage was joined to the remnant vegetation version of the coverage (adapted from Stanton and Stanton 2005) resulting in a combined coverage with both pre-clearing and remnant attributes that can by displayed either as a pre-clearing or a remnant vegetation map.

Confidence in accuracy of the pre-clearing mapping

The accuracy across the pre-clearing coverage varies according to the variety and quality of source data available, and the confidence in interpretation. The Stanton and Stanton (2005) current-day mapping was considered an accurate data source as it is based on standing vegetation visible on recent, large scale (1:25 000) colour aerial photography, and supported by a field sampling component. Old aerial photography was also considered a very useful data source, and the older the better, although the quality (often dependent on the time of day flown, as well as other factors) was also extremely important. The presence of land survey plan information was usually beneficial, although some plans were more useful than others, due to differences in detail of surveyor's notes. Also, on aerial photos some vegetation communities have a very distinct and unique pattern, whilst others are more difficult to distinguish from other similar types.

Separate qualitative reliability codes were assigned for the accuracy of the line-work (boundaries) and polygon attributes based on the above factors. These codes are assigned to each polygon, and are recorded within the map coverage attributes "L" (accuracy of polygon boundary) and "V" (accuracy of vegetation code). The rules and codes used are described in Neldner *et al.* (2005). To create a map of accuracy for the Wet Tropics lowlands, the attributes within "L" and "V" were assigned the scores A=3, B=2, and C=1, then the scores for "L" and "V" for each polygon were combined to produce a score from 2 to 6.

Comparison with previous pre-clearing vegetation coverages

The pre-clearing coverage of the current study was compared with the results of two previous pre-European mapping coverages, Accad (2003), and Johnson *et al.* (2000). The vegetation communities of the current study were grouped to match the groupings used in these studies, and the resulting coverage were compared to each of the previous coverages in turn. The comparison was made by first intersecting the current coverage with the previous coverage (and excluding areas not common to both). Then for each vegetation group a percent similarity was calculated (area of vegetation type "a" where both coverages agree/area of vegetation type "a" in either coverage) X100). Possible reasons for differences between the coverages of the three studies were briefly investigated by examination of the respective project methodologies.

Table 3. Relative proportion of pre-clearing vegetation groups in the Wet Tropics coastal lowlands.

(Vegetation groups occur on alluvium unless specified. "Open forest" and "woodland" here means eucalypt and *Lophostemon* dominated open forest and woodland respectively.)

Vegetation Group	No. of Regional Ecosystems	Area (ha)	% of coastal lowlands
open forests	15	124 450	25
rainforest	11	124 356	24
estuarine	5	55 806	11
teatree	1	38 069	7
woodland	4	37 842	7
paperbark forests	5	37 607	7
grassland and sedgeland	4	28 327	6
dune open forests	2	17 229	3
dune paperbark forests	3	8 580	2
palm swamps	2	7 439	1
open forests on hills	18	7 107	1
rainforest on hills	7	5 438	1
stream beds	1	5 013	<1
dune rainforests vinescrubs	3	4 189	<1
woodland on hills	3	1 356	<1
casuarina	1	1 341	<1
dune casuarina	1	1 323	<1
acacia	1	1 043	<1
dune shrublands and heathlands	2	803	<1
fernland	1	462	<1
teatree on hills	1	174	<1
shrubland on hills	4	46	<1
acacia on hills	2	31	<1
grassland and sedgeland on hills	1	12	0
TOTAL		**508 044**	**100**

Evidence of vegetation manipulation by indigenous inhabitants

Though not a primary aim of this project, some evidence for pre-European manipulation of the environment by the aboriginal inhabitants was noted by the authors, from explorers journals and diaries, and indirectly by visual comparison of the wet tropics pre-clearing vegetation mapping with soils mapping. Some support for this evidence was drawn from the vegetation of the Goorganga Plains of the Central Queensland Coast bioregion (Kemp *et al.* 2001).

Conservation value of vegetation communities and regional ecosystems

An indication of the reduction in area of each vegetation community since pre-clearing times was derived from the vegetation coverage of the current project by comparison of area figures within the pre-clearing attribute and remnant 2003 attribute. This was further broken down into subregions to provide an accurate picture of natural vegetation loss at a subregional level.

Results

Pre-clearing vegetation types and regional ecosystems of the Wet Tropics coastal lowlands

257 vegetation communities, grouped into 98 regional ecosystems, and 24 broad vegetation groups, were mapped in the Wet Tropics coastal lowlands pre-clearing coverage. These are all listed in Appendix 3. The following coloured maps are on the accompanying CD-ROM

Map 1 – Pre-clearing vegetation of the lowlands of the Herbert Subregion, Wet Tropics Bioregion (1:100 000 scale).

Map 2 – Pre-clearing vegetation of the lowlands of the Tully Subregion, Wet Tropics Bioregion (1:100 000 scale).

Map 3 – Pre-clearing vegetation of the lowlands of the Innisfail Subregion, Wet Tropics Bioregion (1:100 000 scale).

Map 4 – Pre-clearing vegetation of the lowlands of the Macalister and Daintree-Bloomfield Subregions, Wet Tropics Bioregion (1:100 000 scale).

The regional ecosystem attribute was chosen for map display, and only the larger pre-clearing mapping areas are shown (minor areas surrounded by remnant vegetation are not included). The full coverage (including both pre-clearing and remnant mapping and both vegetation community and regional ecosystem attributes) can be obtained from the Queensland Herbarium, Environmental Protection Agency, Brisbane.

A summary of the pre-clearing broad vegetation groups across the coastal lowlands is given in Table 3. The most common ecosystems were eucalypt and *Lophostemon* open forests (15 ecosystems; totalling 25% of the coastal lowlands), rainforests (11 ecosystems; 24%) and estuarine systems (5 ecosystems, 11%) (Table 3). Also common were tea-tree woodlands/open forests (1 ecosystem; 7%) eucalypt woodlands (4 ecosystems; 7%), and paperbark open forests (5 ecosystems 7%). Moderately common were grasslands (4 ecosystems; 6%), dune eucalypt forests (2 ecosystems; 3%) dune paperbark open forests (3 ecosystems; 2%) and palm swamps (2 ecosystems 1%) (Table 3). The predominant vegetation on the isolated low hills was eucalypt open forest (18 ecosystems; 1%) and rainforest (7 ecosystems; 1%). A further 12 vegetation groups (21 regional ecosystems) covered the remaining 3% of the lowlands. The dominant soil types found to be associated with each of the most widespread vegetation communities are provided in Table 4.

Lowland pre-clearing vegetation: Herbert subregion

The most common vegetation groups in the Herbert subregion were the eucalypt open forests (11 regional ecosystems, 34% of the subregion), eucalypt woodlands (2 ecosystems, 19%), tea-tree woodlands (1 ecosystem, 12%), grasslands and sedgelands (3 ecosystems 11%) and estuarine systems (5 ecosystems 9%) (Table 5). Dense paperbark forests (5 ecosystems 6%) and rainforests (4 ecosystems 4%) were moderately common to uncommon (Table 5). A further 13 vegetation groups (29 regional ecosystems) made up the remaining 5% of the subregion (each vegetation group around 1% or less).

The fertile lower Herbert River levee and its former courses (including Palm Creek, Trebonne Creek and Cattle Creek), were densely vegetated with forests of *Corymbia tessellaris*, *Melaleuca dealbata*, *Lophostemon suaveolens*, and *Eucalyptus tereticornis* (regional ecosystem (RE) 7.3.9). These were interspersed with poorly drained areas dominated by stands of *Melaleuca leucadendra* and/or *Melaleuca quinquenervia* (REs 7.3.6, and 7.3.5). Rainforest was generally restricted to the best-drained and most fertile soils; (usually narrow creek and river levees), and took the form of a semi-deciduous notophyll to mesophyll vine forest (RE 7.3.23), or more commonly, a vine forest with emergent *Melaleuca leucadendra* (RE 7.3.25). In a few places, rainforest (RE 7.3.23) covered wider areas such as at the junction of the Stone and Herbert Rivers (approximately 300 Ha), and Gowrie Creek (400Ha), and also the mouth of the Herbert River in the Macknade/Halifax area where broad expanses of rainforest (approx 1700Ha) were interspersed with pockets of *Eucalyptus tereticornis* open forest.

The swampy, seasonally inundated back-plains of the main central and eastern Herbert River floodplain supported large expanses of open grassy plains, sedge-swamps, and lagoons. These included tongues of better-drained soils supporting

Table 4. List of vegetation communities and their dominant soil types. Only vegetation communities > 1000 ha in the soils/vegetation intersect coverage are shown.

The four soil types covering the greatest percent area of the vegetation community are listed (only soils > 5% are shown). Full names and descriptions of soil types are in Canon et al. (1992), Murtha (1986), Murtha (1989), Murtha et al. (1996), and Wilson & Baker (1990).

Vegetation Community	Soil type (% area of vegetation community)
7.1.1	UCG (72), Mg (16)
7.1.2a	UCG (67), Mg (12), ML (10)
7.2.1a	Br (74), Hu (12)
7.2.3a	Hu (63), Cs (10), DLU (7), UCG (6)
7.2.3d	Hu (61), Dt (15), Tk (6)
7.2.3e	Hu (36), Br (26), Ta (13)
7.2.3f	Hu (47), Ka (17), Ku (10), Cs (8)
7.2.4a	Sp (33), Hu 16, Ku (11), Br (11)
7.2.4b	Hu (36), Sp (33), H3 (6)
7.2.8	Hu (50), UCG (13), CS (9)
7.2.9a	Ne (25), Hu (15), Hc (15), Ku (8)
7.3.1a	He (24), Co (17), Bg (15), He Dv (12)
7.3.1b	Hl (64), Tb (17), Ih (6)
7.3.3a	Ti (30), Tu (13), Co (12)
7.3.4	Co (37), Tu (20), Ti (10), Th (6)
7.3.5a	He (20), Nd (13), Bu (13), Co (7)
7.3.6a	DLU (30), Hl (15), Tb (15), Tr (11)
7.3.7a	Tu (14), Bg (13), Th (12), Ma (8)
7.3.7b	Tu (27), Co (11), Ct (8), Ma (7)
7.3.8a	Lu (14), Cm (12), Pt (11), Th (7)
7.3.8b	As (14), Ln (14), Yr (9), Hl (9)
7.3.8c	Th (28), Lu (11), He (8), Co (7)
7.3.9a	Tb (27), Pl (13), Hb (12), Ih (10)
7.3.10a	Tu (24), Th (10), Li (9), Ms (7)
7.3.10e	Co (25), Tu (24), Ti (11), Ra (5)
7.3.12a	Th (11), Co (8), Tu (7), Li (6)
7.3.12b	Co (17), Tb (11), Bg (10), Tu (9)
7.3.12e	Th (31), Lu (15), Wm (13), Co (10)
7.3.16a	As (12), Mn (11), Ln (10), Hv (9)
7.3.16b	Ag (20), Mn (13), As (13), Bw (11)
7.3.16c	Yr (49), As (19), Hl (18), Ln (9)
7.3.17	Tu (31), Li (22), In (21)
7.3.19a	Bw (20), Hv (19), Cn (11), Th (11)
7.3.20a	Th (10), Pr (7), Vi (6), Ga (5)
7.3.20b	Th (13), Tu (8), Co (7), Ty (7)
7.3.20e	TH (23), Hv (18), Bw (13), Le (7)
7.3.21a	Hv (32), Th (19), Bw (10), HvFv (7)
7.3.23a	Li (30), Hb (20), Mk (13), In (8)
7.3.25a	Mk (13), STC (19),
7.3.28a	Li (31), STC (25), Tu (13)
7.3.32a	Tb (28), Mm (18), Tu (7), Tr (5)
7.3.34	Hl (34), Lh (15), Rp (7), Ln (5)
7.3.40	Vi (12), Th (9), Hb (9), Mk (6)
7.3.44	Ct (26), Ms (19), Bw (9), Cl (8)
7.3.45b	Mn (16), Ms (11), Cl (8), Hv (8)
7.3.45e	Tb (22), Hv (13), Th (13), Hb (9)
7.3.45f	Il (32), Cl (25), Jr (8), Bg (7)
7.3.46	Ag (17), Hb (9), Hl (9), Tb (8)
7.8.1a	Pg (81)
7.8.1b	Eu (85)
7.11.1a	Ga (53), MTN (19), Bi (6), Pg (5)
7.12.1a	Ga (34), MTN (25), Ut (21)

grasslands of *Imperata cylindrica* (RE 7.3.1), as well as hard-setting clay plains with swamp grasses and sedges (RE 7.3.32), and deep permanent lagoons (RE 7.3.29). These formed a virtually continuous plain east from Trebonne almost to Forrest Beach, and south from the Herbert River to Trebonne Creek, and included the plains surrounding Lucy Creek, Cattle Creek and the area now under Ingham township. Figure 2 shows a treeless swamp/grasslands complex in the Cattle Creek/Pomona area which still remains today.

The slightly more elevated back-plains supported extensive *Melaleuca viridiflora* woodlands and open forests (RE 7.3.8), *Eucalyptus platyphylla* woodlands (RE 7.3.16), and in some places (eg. Mountain Creek/Spring creek valley in the vicinity of Pappins Rd.), *Eucalyptus tereticornis* woodlands and open forests (RE 7.3.40). Some areas (still present in Wharps and Lannercost holdings) were laced by numerous narrow bands of the moderately well-drained soils of prior streams, which supported either dense stands of *Lophostemon suaveolens* (RE 7.3.46) or mixtures of *Lophostemon suaveolens, Eucalyptus platyphylla* and *Corymbia clarksoniana* (vegetation community 7.3.16b).

Table 5. Relative proportion of pre-clearing vegetation groups in the Herbert subregion.

(Vegetation groups occur on alluvium unless specified. "Open forest" and "woodland" here means eucalypt and *Lophostemon* dominated open forest and woodland respectively.)

Vegetation Group	No. of Regional Ecosystems	Area (ha)	% of Herbert subregion
open forests	11	61 632	32
rainforest	4	8 530	4
estuarine	5	17 153	9
teatree	1	23 533	12
woodland	2	36 838	19
paperbark forests	5	11 848	6
grassland and sedgeland	3	21 606	11
dune open forests	2	2 372	1
dune paperbark forests	3	991	<1
palm swamps	1	225	<1
open forests on hills	10	1 780	<1
rainforest on hills	2	59	<1
stream beds	1	2 761	1
dune rainforests vinescrubs	3	368	<1
woodland on hills	2	1 306	<1
casuarina	1	1 305	<1
dune casuarina	1	594	<1
acacia	1	60	<1
dune shrublands and heathlands	0	0	0
fernland	0	0	0
teatree on hills	1	52	<1
shrubland on hills	1	3	0
acacia on hills	0	0	0
grassland and sedgeland on hills	0	0	0
TOTAL		**193 016**	**100**

The fertile upper Herbert River (including Abergowrie) and Stone River valleys contained extensive areas of eucalypt and swamp mahogany open forest, predominantly mixtures of *Lophostemon suaveolens, Eucalyptus platyphylla* and *Corymbia clarksoniana* (vegetation community 7.3.16b), and also broad expanses of *Lophostemon suaveolens* open forest (RE 7.3.46), and areas of *Eucalyptus platyphylla* woodland (vegetation community 7.3.16a). Figure 3 illustrates a portion of this area in 1943. Open forests of *Corymbia clarksoniana* (RE 7.3.45) were common along the central and upper Stone River levee.

The upper alluvial fans such as those of the upper Herbert/Abergowrie area supported relatively dense/tall forests of *Corymbia intermedia, Syncarpia glomulifera, Eucalyptus pellita, Allocasuarina* spp. *Eucalyptus cloeziana* and *Corymbia torelliana* (RE 7.3.20).

A mangrove ecosystem of variable floristic composition (RE 7.1.1) lined the more sheltered northern coast of the Herbert River delta, whilst areas south of Forrest Beach were a mixture of mangroves (RE 7.1.1) saltpan (vegetation community 7.1.2a), *Sporobolus virginicus* grasslands (vegetation community 7.1.2b), and *Schoenoplectus litoralis* swamps (RE 7.1.3). An extensive area of re-worked alluvium, mangrove silt and dune sands occurred in the Orient area, supporting a mixture of estuarine communities and eucalypt, *Acacia* and *Melaleuca viridiflora* open forests (REs 7.3.9 and 7.2.4). The majority of these estuarine complexes remain intact today.

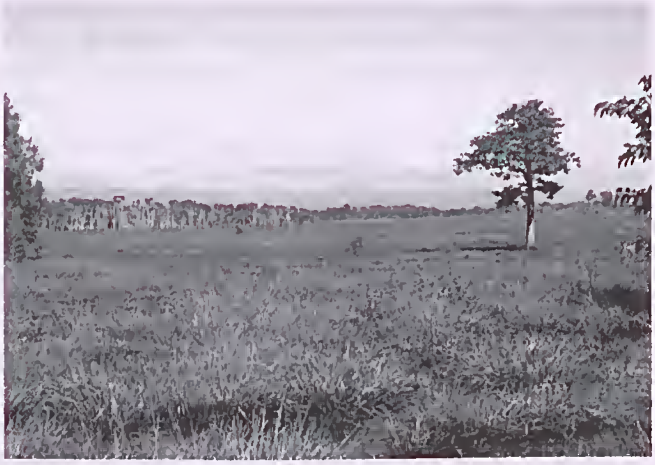

Fig. 2. Swamps of the Cattle Creek floodplain in the Pomona area south of Ingham with sedges, swamp grasses and aquatic herbs (RE 7.3.29a). The swamp features occasional isolated trees such as *Nauclea orientalis* (right hand centre), and is bordered by natural thickets of *Melaleuca quinquenervia*. Swamps such as these were common across the Herbert floodplain.

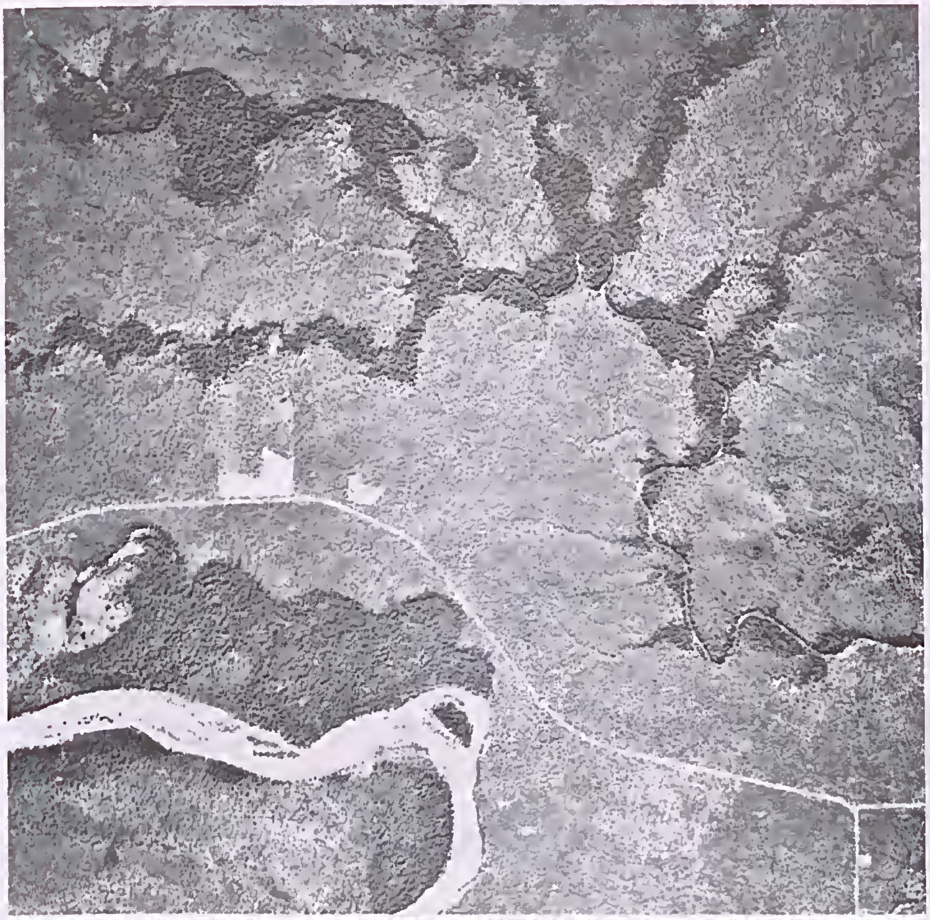

Fig. 3a. 1943 aerial photo (1:34 000 scale) of the upper Herbert floodplain showing the Herbert River, the Ingham-Abergowrie Road, and Elphinstone and Broadwater Creeks (distance across photo is approximately 2.5 km). Although there is clear evidence of disturbance and logging, these photos provide excellent evidence of the former vegetation in this now largely-cleared valley. Dark patterns were rainforest (RE 7.3.23) whilst the (lighter patterned) sclerophyll vegetation was open forest of *Eucalyptus platyphylla*, *Lophostemon suaveolens* and *Corymbia clarksoniana* (REs 7.3.16a, 7.3.16b, and 7.3.46).

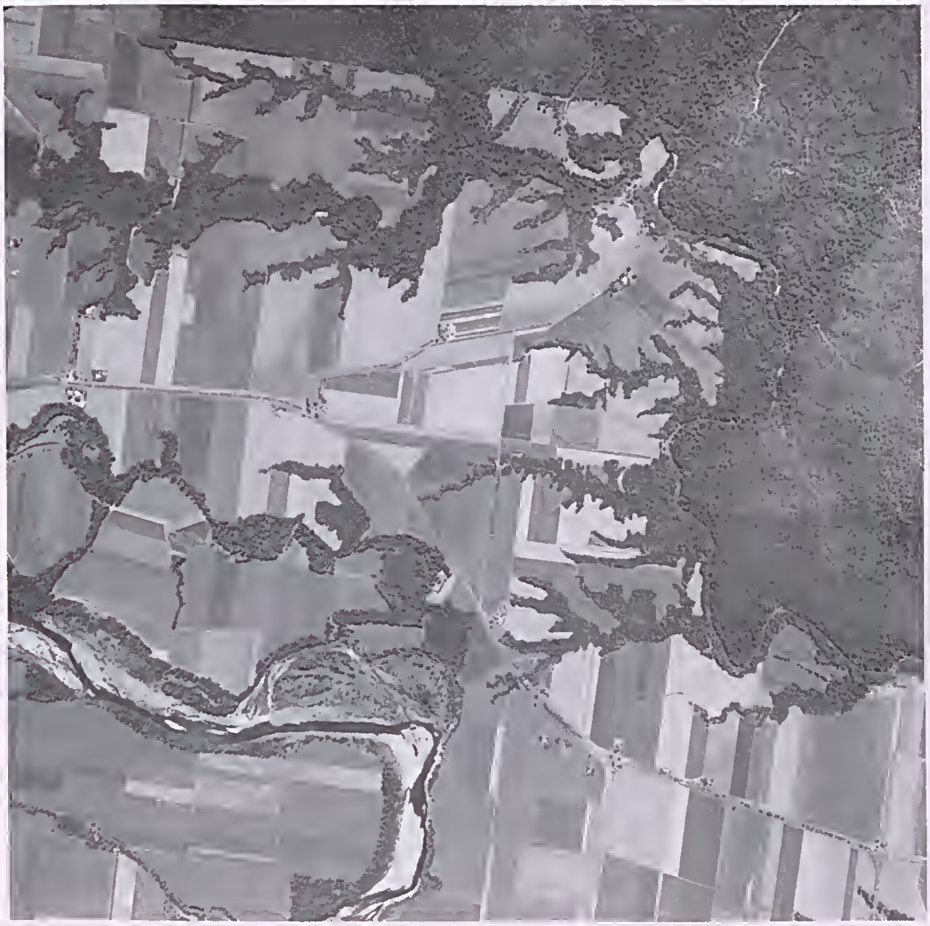

Fig. 3b. 2006 aerial photo of the same area.

The southern, drier parts of the Herbert subregion form a long narrow band of alluvium from Crystal Creek to Bluewater, and were dominated by a complex of *Corymbia clarksoniana*, *Eucalyptus drepanophylla* and *Corymbia tessellaris* open forests and woodlands (RE 7.3.45), *Melaleuca viridiflora* woodlands (RE 7.3.8), and *Eucalyptus platyphylla* woodlands and open forests (RE 7.3.16). A relatively large proportion of this remains uncleared to this date.

Lowland pre-clearing vegetation: Tully subregion

The most common vegetation groups in the Tully subregion were the eucalypt open forests (11 regional ecosystems, 28% of the subregion), rainforests (6 ecosystems, 19%), estuarine systems (4 ecosystems, 16%), paperbark forests (4 ecosystems, 11%) and tea-tree woodlands/open forests (1 ecosystem, 10%) (Table 6). Also moderately common were dune open forests (2 ecosystems, 5%), grasslands and sedgelands (4 ecosystems, 4%), dune paperbark forests (3 ecosystems, 2%), eucalypt open forests on low isolated hills (7 ecosystems, 2%), and palm swamps (2 ecosystems, 2%) (Table 6). A further 8 vegetation groups (12 regional ecosystems) made up the remaining 1% of the subregion (each vegetation group less than 1%).

The stretch of narrow alluvial fans from Lucinda to Cardwell, mainly supported (as it still does today) mangroves (RE 7.1.1), and *Melaleuca viridiflora* open forest (RE 7.3.8), with alluvial fans and creek levees often characterised by *Eucalyptus portuensis* open forest (RE 7.3.21). The deeper soils of the alluvial fans supported forests of *Corymbia intermedia*, *Syncarpia glomulifera*, *Eucalyptus pellita*, *Allocasuarina* spp. and *Eucalyptus cloeziana* (RE 7.3.20). The flat alluvial plains contained areas of *Corymbia clarksoniana* and *Corymbia tessellaris* open forest (RE 7.3.45), and even outlying stands of *Eucalyptus leptophleba* (RE 7.3.44) (more common on the lowlands north of Cairns). Areas of *Melaleuca quinquenervia* occur along narrow drainage lines amongst *Melaleuca viridiflora* open forests, and around the edges of mangroves.

These ecosystems extended north into the southern half and alluvial fans of the Kennedy Valley. The central Kennedy Valley also supported extensive areas of what appears to have been low woodlands with mixed *Melaleuca viridiflora* and *Melaleuca quinquenervia* with scattered *Eucalyptus tereticornis* (vegetation community 7.3.12c). Open forests and woodlands of *Eucalyptus tereticornis* on better-drained soils (RE 7.3.12) extended to the base of the mountain ranges, particularly on the northern and western fans of the valley. A band of mesophyll vine forest (RE 7.3.10) cloaked the levees of the Kennedy, Alma, Boggy Camp and Meunga creeks.

The stretch of alluvial lowlands from the Kennedy Valley to the main Murray floodplain occurs on fairly old alluvial systems with poorly drained soils, and was a mixture of *Melaleuca viridiflora* open forests, low woodlands of mixed *Melaleuca viridiflora* and *Melaleuca quinquenervia* with

Table 6. Relative proportion of pre-clearing vegetation groups in the Tully subregion.

(Vegetation groups occur on alluvium unless specified. "Open forest" and "woodand" here means eucalypt and *Lophostemon* dominated open forest and woodland respectively.)

Vegetation Group	No. of Regional Ecosystems	Area (ha)	% of Tully subregion
open forests	11	36 179	28
rainforest	6	25 323	19
estuarine	4	21 502	16
teatree	1	12 543	10
woodland	1	42	<1
paperbark forests	4	14 348	11
grassland and sedgeland	4	5 019	4
dune open forests	2	6 460	5
dune paperbark forests	3	2 845	2
palm swamps	2	2 168	2
open forests on hills	7	2 543	2
rainforest on hills	3	753	1
stream beds	1	687	<1
dune rainforests vinescrubs	3	304	<1
woodland on hills	0	0	0
casuarina	0	0	0
dune casuarina	1	223	<1
acacia	1	25	<1
dune shrublands and heathlands	1	298	<1
fernland	0	0	0
teatree on hills	1	122	<1
shrubland on hills	0	0	0
acacia on hills	0	0	0
grassland and sedgeland on hills	0	0	0
TOTAL		**131 383**	**100**

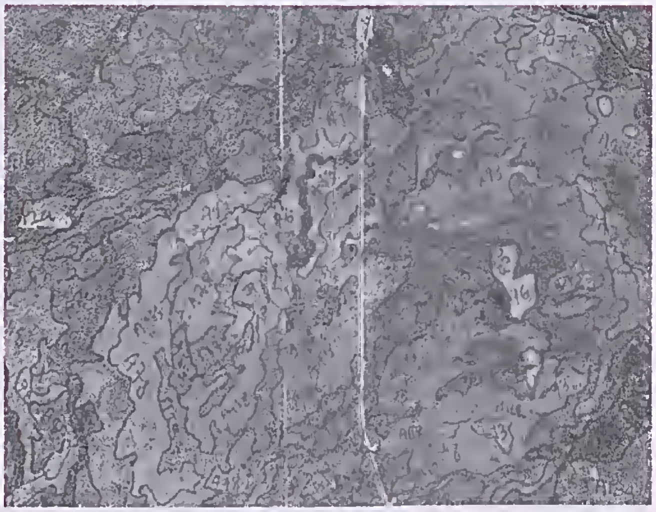

Fig. 4. Pre-clearing linework drawn on a 1961 (1:80 000) aerial photo of the almost flat Tully-Murray floodplain, showing the complex array of small vegetation units due to changes in soils and slight changes in topography.

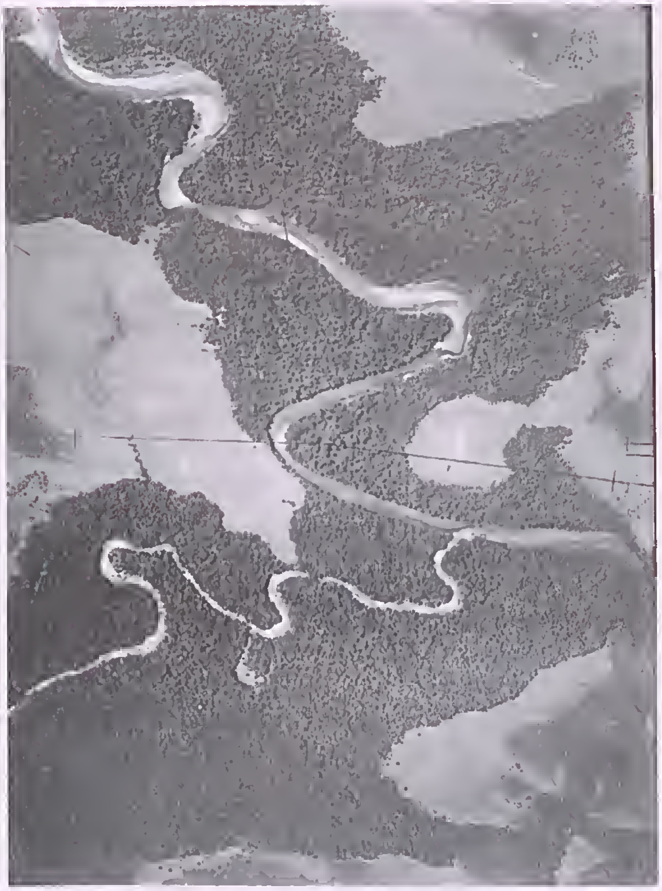

Fig. 5a. 1937 aerial photo of a part of *Munro Plains* (junction of the Tully River and Davidson Creek), showing the natural grasslands of the plains (RE 7.3.32a) terminating abruptly at the dense rainforests of the Tully River levee (RE 7.3.17). (Distance across photo is approximately 2.5 km)

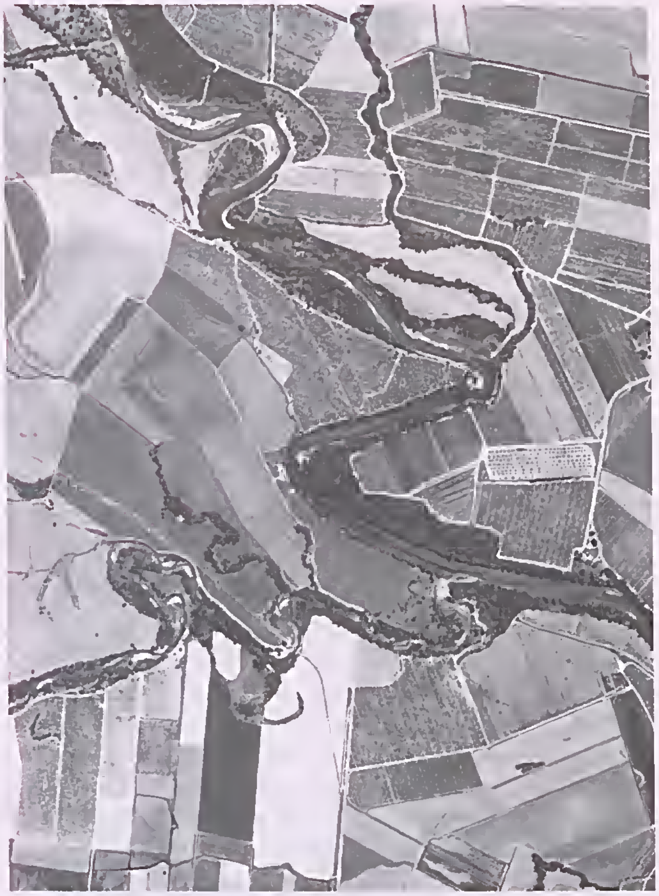

Fig. 5b. The same area in 2000.

scattered *Eucalyptus tereticornis* (vegetation community 7.3.12c), and *Melaleuca quinquenervia* swamps (RE 7.3.5).

The main Tully-Murray floodplain was an extraordinarily diverse and complex mosaic of vegetation communities and ecosystems. Vegetation community (and/or regional ecosystem) patch size was relatively small, but their occurrences numerous amongst other vegetation communities (and/or regional ecosystems). Visually the result on the pre-clearing vegetation/regional ecosystem maps is a bewildering array of small polygons (Figure 4). The main vegetation types on the older alluvial surfaces included *Melaleuca viridiflora* woodlands/open forests (RE 7.3.8), low woodlands with mixed *Melaleuca viridiflora*, and *Melaleuca quinquenervia* with scattered *Eucalyptus tereticornis* (vegetation community 7.3.12c), and open forests of *Eucalyptus pellita* and *Corymbia intermedia* (RE 7.3.7). Numerous small depressions in the landscape usually supported stands of *Melaleuca quinquenervia* (RE 7.3.5). Areas with better soils associated with younger alluvium supported mixtures of *Eucalyptus tereticornis* open forest (RE 7.3.12 and 7.3.40) and mesophyll vine forest (7.3.10) often with associated *Licuala ramsayi* swamps (RE 7.3.4). This area included what appears to have been the largest *Licuala ramsayi* swamp to have existed in the bioregion (234 Ha in area) (exceeding by 65 Ha the large "Licuala palms" tourist destination which still stands near Mission Beach.). Small, numerous low acid igneous rises in the central west of the floodplain were clothed in *Eucalyptus pellita* and *Corymbia intermedia* open forests (RE 7.12.5), and simple-complex mesophyll-notophyll vine forest (RE 7.12.1).

The fertile levees of the Tully River and Jarrah Creek supported an impressive belt of complex mesophyll vine forest (RE 7.3.17) averaging around 1km wide for it's entire length (approximately 2.4 km across at it's broadest). Associated with the edges/backplains of this levee were relatively extensive open grassy plains (eg the "Munro Plains" area) (vegetation community 7.3.32a) (Figure 5). These plains were often immediately adjacent to the main belt of the Tully River complex mesophyll vine forest. An abrupt, clear-cut boundary (with no gradation) between the rainforest and grassland was common. With very little remaining today to judge their composition it is assumed that these grasslands may have contained *Imperata cylindrica*, *Sarga* spp., *Sorghum nitidum* forma *aristatum*, and swamp grasses such as *Ischaemum australe*. Grasslands appear to have been swampier to the south of the Tully River, in the area surrounding the central Murray River (the area known as the "Bellenden Plains"), and contained numerous open swamps with standing water (RE 7.3.29).

The floodplain immediately north of the Tully township (Feluga area) was cleared very early in the history of European settlement, but apparently supported an extensive area of rainforest (probably RE 7.3.17) covering the entire western half of the valley (over 3km at it's broadest), with swampier rainforests in the central and eastern parts (RE 7.3.10) tending to swamps of *Licuala ramsayi* (RE 7.3.4), and *Melaleuca quinquenervia* (RE 7.3.5). Small pockets of eucalypt open forest were mainly dominated by *Eucalyptus pellita* and *Corymbia intermedia* (REs 7.3.7 and 7.3.20).

The broad expanse of dunes which extend from Cardwell to just north of the Tully River are an extensive Pleistocene system. An enormous range of woodland and forest types occurred on these varied sandy soils, including numerous vegetation communities of the RE 7.2.4 (*Corymbia intermedia*, *Eucalyptus pellita* and *Lophostemon suaveolens* open forest). This regional ecosystem includes an unusual vegetation community dominated by *Eucalyptus portuensis* on dune sands, which can be found on the northern outskirts of Cardwell. Other Pleistocene dune communities included *Melaleuca viridiflora* open forests (RE 7.2.11), and *Melaleuca quinquenervia* swamps (RE 7.2.9). Backed up against this massive dune system were extensive areas of alluvial *Melaleuca quinquenervia* (RE 7.3.5) associated with the regular trapping of floodwaters against the dunes.

The younger (Holocene) dunes, in closer proximity to the ocean, typically supported *Corymbia tessellaris*, *Acacia crassicarpa* and *Corymbia* spp. (RE 7.2.3), as well as swampy swales with *Melaleuca leucadendra*, and low dune ridges with stands of mesophyll to microphyll vine forests (REs 7.2.2 and 7.2.5). The majority of these Holocene dune ecosystems in the Tully subregion remain intact today.

Extensive mangrove and estuarine systems (mainly RE 7.1.1) occurred in the central and northern parts of the Tully subregion, and include substantial areas which fluctuate between freshwater and saltwater assisted by irregular flooding rains caused by cyclones (RE 7.1.3).

Lowland pre-clearing vegetation: Innisfail subregion

By far the most common and widespread vegetation group in the Innisfail subregion was rainforest, which consisted of 10 regional ecosystems and covered 52% of the subregion (Table 7). Open forests were fairly common as pockets within rainforest or as parts of near-coastal complexes or on low hills (13 ecosystems, 13%). Estuarine systems were moderately prominent (4 ecosystems, 8 %) as were paperbark forests (4 ecosystems, 7%), and dune eucalypt open forests

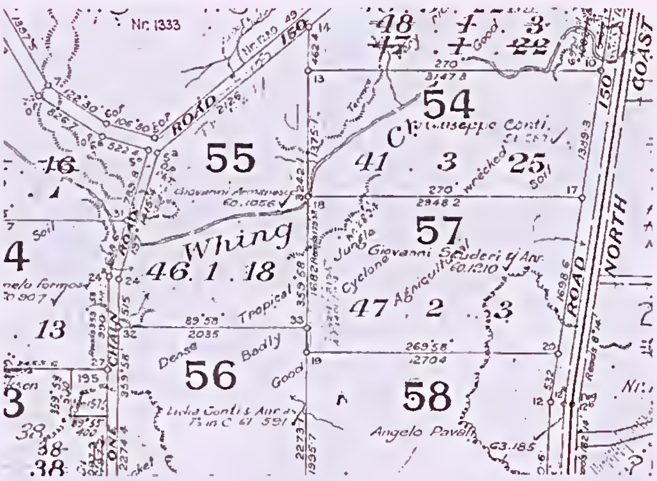

Fig. 6. 1920 survey plan of the El Arish (near Tully) area showing that most of the floodplain was covered in rainforest (eg *tropical jungle* and that much of it was *badly cyclone wrecked*) at the time.

Table 7. Relative proportion of pre-clearing vegetation groups in the Innisfail subregion.

(Vegetation groups occur on alluvium unless specified. "Open forest" and "woodland" here means eucalypt and *Lophostemon* dominated open forest and woodland respectively.)

Vegetation Group 2	**No. of Regional Ecosystems**	**Area (ha)**	**% of Innisfail subregion**
open forests	13	20 095	13
rainforest	10	79 224	52
estuarine	4	11 474	8
teatree	1	1 489	<1
woodland	0	0	0
paperbark forests	4	10 030	7
grassland and sedgeland	4	1 701	1
dune open forests	2	6 875	5
dune paperbark forests	3	3 913	3
palm swamps	2	4 326	3
open forests on hills	11	2 087	1
rainforest on hills	5	4 251	3
stream beds	1	1 290	<1
dune rainforests vinescrubs	3	2 443	2
woodland on hills	0	0	0
casuarina	1	37	<1
dune casuarina	1	336	<1
acacia	1	772	<1
dune shrublands and heathlands	1	505	<1
fernland	1	459	<1
teatree on hills	0	0	0
shrubland on hills	3	23	<1
acacia on hills	2	31	<1
grassland and sedgeland on hills	1	9	<1
TOTAL		**151 368**	**100**

(2 ecosystems, 5%). Less prominent but still relatively common were palm swamps (2 ecosystems, 3%), rainforest on low isolated hills (5 ecosystems, 3%), dune paperbark forests (3 ecosystems, 3%), dune vinescrubs (3 ecosystems, 2%), eucalypt open forest on hills (11 ecosystems, 1%) and grasslands and sedgelands (4 ecosystems, 1%). A further 10 vegetation groups comprising 13 regional ecosystems covered the remaining 2% of the subregion.

The southern end of the subregion (east of Feluga and along the Tully Mission Beach Road) consisted of a mixture of swampy sclerophyll types and rainforest. Swamps of *Melaleuca quinquenervia* (RE 7.3.5) were common especially adjacent to mangroves, changing on slightly higher ground to *Melaleuca viridiflora* open forests (RE 7.3.8) (of a rather sandier soil than more southern examples), and *Eucalyptus pellita* and *Corymbia intermedia* open forests (RE 7.3.7). Rainforests were often of the moderately to more poorly-drained variety (vegetation communities 7.3.10a and 7.3.10c), and towards Mission Beach there was a vast *Licuala ramsayi* forest (7.3.4) which is the second largest example of this regional ecosystem to have existed (and still exists today).

The Mission Beach area was a mixture of rainforests, swamps and dune scrubs including, in the northern Mission Beach area, an extensive zone of complex mesophyll vine forest on basalt (RE 7.8.1). Rainforests on alluvium (RE 7.3.10) were also common here, including swampy rainforest communities and tending to palm swamps (REs 7.3.3 and 7.3.4). A prominent Holocene dune system supported substantial areas of dune vine scrub (REs 7.2.5 and 7.2.1), as well as eucalypt open forests of *Corymbia tessellaris* and *Corymbia* spp. (RE 7.2.3). The swampy swales often supported stands of *Melaleuca leucadendra* (RE 7.2.8) or *Melaleuca quinquenervia* (RE 7.2.9).

The Kurrimine Beach area is the location of an extensive Pleistocene and Holocene beach ridge system which supported large areas of *Melaleuca quinquenervia* (RE 7.2.9) as well as *Eucalyptus pellita* and *Corymbia intermedia* open forests (RE 7.2.4). Much of this remains today. An extensive swampy sclerophyll alluvial plain once extended from this dune system, to beyond Silkwood – as far west as the Old Silkwood area, and south almost to El Arish. This was dominated by *Eucalyptus pellita* and *Corymbia intermedia* interspersed with many small swamps of *Melaleuca*

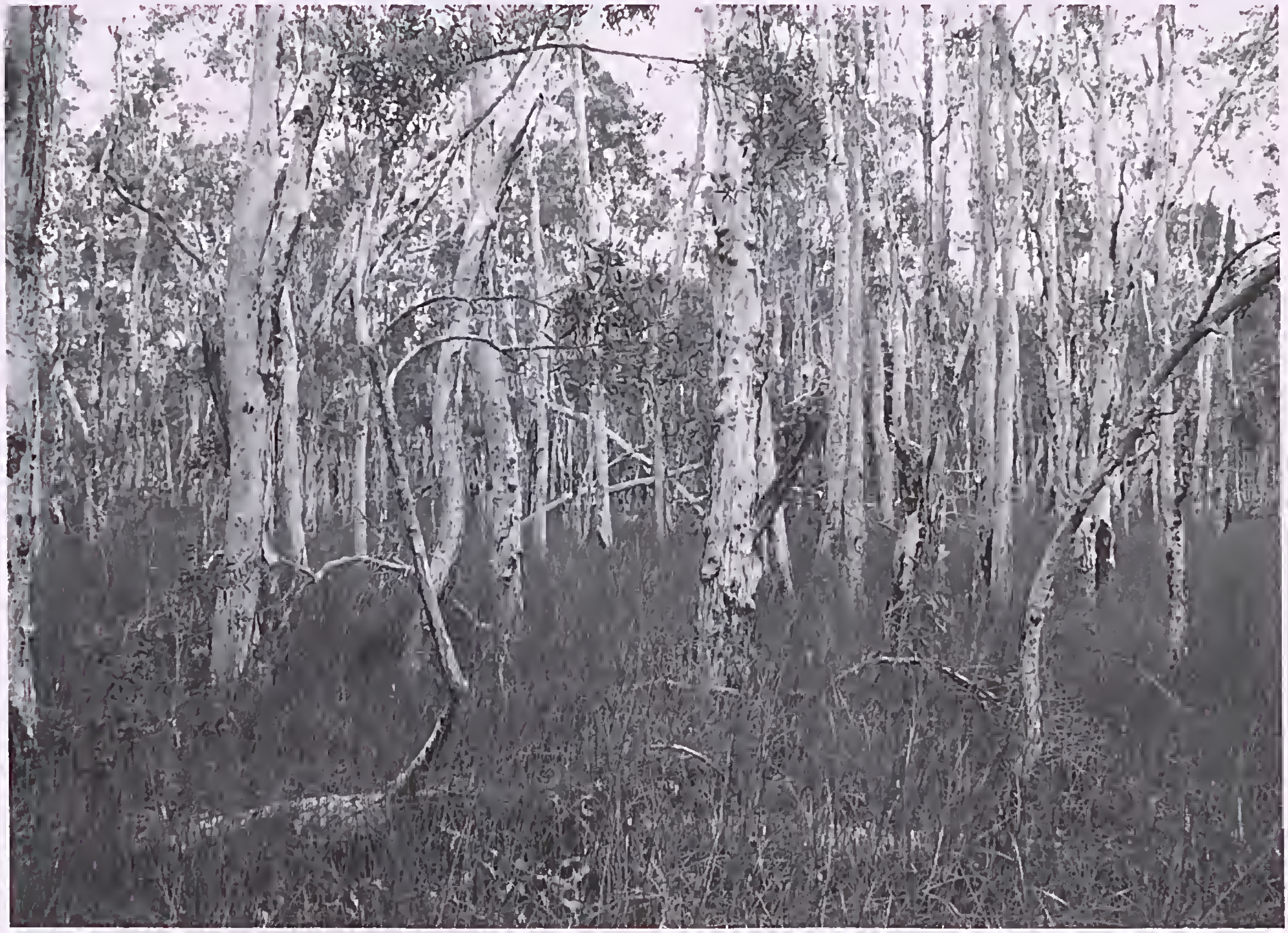

Fig. 7. *Melaleuca quinquenervia* forest (RE 7.3.5) in the Tully area.

quinquenervia and occasional areas of *Melaleuca viridiflora* woodland, and *Archontophoenix alexandrae* swamps. A large area of *Acacia mangium* and/or *Acacia celsa* open forest (RE 7.3.35) occurred towards the northern end of this sclerophyll zone.

The remaining central and western floodplain (El Arish/Silkwood/Japoonvale) was covered in either complex mesophyll vine forest (RE 7.3.17) (mainly the more fertile creek levees), or simple-complex mesophyll to notophyll vine forest (RE 7.3.10) interspersed with small pockets of relatively dense eucalypt forest (eg *Corymbia intermedia* open forest RE 7.3.19). The rainforest in this valley appears to have been heavily cyclone damaged at the time that the original land survey plans were drawn up (Figure 6).

The largest Pleistocene dune system in the bioregion was divided by the mangroves of the Moresby River and Mourilyan Creek, and occurred from Cowley Beach inland to almost as far west as Martyville near the Bruce Highway (3km south of Mourilyan), and north almost to Etty Bay. Most of this is now cleared, but it appears to have supported large areas of complex mesophyll or mesophyll vine forest (RE 7.2.1), and would have been by far the largest occurrence of dune vine forests in the Wet Tropics. The extensive Cowley Beach Holocene dune system to the east of the mangroves remains intact today, and is supported by a swampy complex of *Melaleuca quinquenervia* shrublands and open forests, and *Melaleuca viridiflora, Lophostemon suaveolens* and *Allocasuarina littoralis* open forests (REs 7.2.11 and 7.2.9), as well as areas of *Acacia crassicarpa* dominated open forest (RE 7.2.9).

Behind the dunes lay an extensive belt of alluvial rainforest from as far north as the North Johnstone River south to Liverpool Creek (Cowley), including the better developed complex mesophyll vine forest (RE 7.3.17) on the more fertile creek levees, and simple-complex mesophyll to notophyll vine forest (RE 7.3.10) on the surrounding lowlands. This includes the township of Innisfail (where there are also metamorphic rises which supported complex mesophyll rainforest (RE 7.11.1). To the west of South Johnstone, the entire Palmerston area, and the north-west of Mena Creek are part of an extensive basalt flow, and once supported the most well-developed and complex of wet tropics rainforest ecosystems - complex mesophyll vine forest on basalt (RE 7.8.1). This was indeed a vast expanse, covering over 11,000 hectares. Eastern edges of the basalt flow probably supported a poorer, swampier type of basalt rainforest (vegetation community 7.8.1b) on the more poorly drained Eubenangee soil series (Murtha 1986), though evidence of the existence of this vegetation community (ie remnant rainforest patches) are now scarce.

From the North Johnstone River through to Babinda (east of the Bruce Highway) was a mixture of undulating metamorphic and basalt rises, interspersed with low, often swampy areas, mainly forested with simple to complex mesophyll to notophyll rainforest (RE 7.3.10), *Archontophoenix alexandrae* forests (RE 7.3.3), and *Melaleuca quinquenervia* open forests (RE 7.3.5) (Figure 7). A few small open grassy plains (RE 7.3.1) were found in this area, and were best developed at Eubenangee (extending further east and north from the current grassland extent at Eubenangee Swamp today). As well as extensive *Melaleuca quinquenervia* open forests, and *Archontophoenix alexandrae* forests (RE 7.3.3), southern parts of the Babinda swamp appeared to have supported a kind of open sedge/fern swamp with scattered pioneering rainforest shrubs and trees (RE 7.3.30).

From the Russell River Valley through to Quingilli (about 8km SE of Gordonvale) was a more or less continuous valley of rainforest and palm swamps. The broad fertile levees of the mid and upper Russell River, and the Babinda Creek supported complex mesophyll vine forest (RE 7.3.17), whilst the surrounding plains a more simple to complex notophyll to mesophyll vine forest (RE 7.3.10), and numerous sizeable *Archontophoenix alexandrae* swamps (RE 7.3.3). The broad Mulgrave River levee apparently supported a drier form of levee rainforest: a simple-complex semi-deciduous notophyll to mesophyll vine forest (RE 7.3.23), perhaps due to the gradual decrease in rainfall north (from the highest rainfall area around Mirriwiini, near Babinda).

North of Quingilli through Gordonvale and Edmonton areas, sclerophyll forest became prominent again, corresponding with the drop in rainfall. Open forests of *Eucalyptus tereticornis* (REs 7.3.40 and 7.3.12) were common, along with dense stands of *Melaleuca dealbata, Lophostemon suaveolens* and *Corymbia tessellaris* (RE 7.3.9) and occasional *Melaleuca quinquenervia* swamps (RE 7.3.5). Two open grassy plains occurred to the east and south-east of Aloomba.

The Mulgrave River valley was mostly rainforested, with either rainforest on alluvium (RE 7.3.23 on the levees and 7.3.10 on the surrounding alluvium) or on basalt (RE 7.8.1 on the flats and RE 7.8.14 on the foothills)

The broad, very flat floodplain from Gordonvale to Redbank (south of Trinity Inlet) appears to have been forested in a somewhat puzzling very extensive low dense forest of *Acacia* species, *Corymbia clarksoniana, Melaleuca dealbata, Melaleuca viridiflora* and *Melaleuca quinquenervia* (the apparently extinct vegetation community 7.3.45f). Better-developed bloodwood forests (RE 7.3.45b) were common to the south and west of this area. Two isolated basalt hills (Green Hill, and a smaller hill immediately north-west of Meringa – 2km NW of Gordonvale) were clothed in complex mesophyll vine forest (RE 7.8.1) and grassland (vegetation community 7.8.7c), and on Green Hill, a eucalypt open forest consisting of *Corymbia intermedia* and *Eucalyptus tereticornis* (RE 7.8.18).

The south-eastern edge of Trinity Inlet consists of a narrow strip of alluvium having similar vegetation to the plain further south, but it is also the site of a vegetation community which was very rare even in pre-clearing times – *Melaleuca cajuputi* open forest (RE 7.3.5c). The only other occurrence of this vegetation type that has been confirmed from remnants in the field is just south of the Daintree River. Other pre-clearing occurrences have been mapped just south of Mossman and near Cowley Beach, however the confidence ratings are low given the difficulty in identifying the photo-pattern on the aerial photographs used for these areas.

The marine plain immediately opposite Cairns (east of the mouth of Trinity Inlet) was covered in mangroves and saltpans, with a few narrow parallel dunes mostly forested with *Melaleuca leucadendra* (RE 7.2.8). The 1942 mangrove shore-line was several hundred metres further inland than it is today (over 1km further inland at the area of greatest expansion). The landward edge of the estuarine area was bordered by a narrow fringe of alluvium supporting a mixture of *Eucalyptus tereticornis* open forest (RE 7.3.12), *Melaleuca quinquenervia* swamps (Re 7.3.5), rainforest (RE 7.3.10) and open forests of *Eucalyptus pellita*, and *Corymbia intermedia* (RE 7.3.20).

The area under what is now Cairns city was formerly an extensive series of long, very narrow (eg frequently only 40–50m wide), low pro-grading dunes separated by even narrower (commonly 25–30m wide) swales. The dune crests supported *Corymbia* spp. and *Corymbia tessellaris* open forests (RE 7.2.3), whilst the swales often contained mangroves (RE 7.1.1), dense swampy paperbark forests (REs 7.2.8 and 7.2.9), *Archontophoenix alexandrae* swamps (vegetation type 7.2.1g) or swampy rainforest (vegetation type 7.2.1d) (Figure 8).

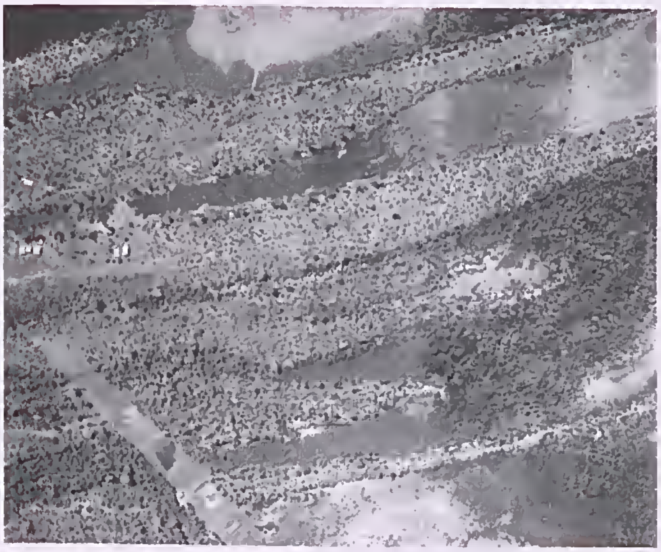

Fig. 8. Part of a 1937 aerial photo (1:7000 scale) of the Cairns city area, clearly showing the series of narrow forested/shrubby dune ridges and swampier mangrove-filled swales.

Immediately west and south-west of Cairns at the base of the Whitfield Range the vegetation was formerly a mixture of rainforest (RE 7.3.10), *Eucalyptus tereticornis* open forests (RE 7.3.12) and *Corymbia clarksoniana* open forests (RE 7.3.45) with a few patches of *Melaleuca viridiflora* open forest and woodland (RE 7.3.8). The Redlynch/Freshwater valley was mostly rainforest, with the main river levee supporting a simple-complex semi-deciduous notophyll to mesophyll vine forest (RE 7.3.23), and surrounding plains with simple-complex mesophyll to notophyll vine forest (RE 7.3.10). The western slope of the valley may have supported better-developed rainforest (complex mesophyll vine forest, RE 7.3.17) due to the presence of a deep fertile soil which includes the associated Kimberley soil unit that has a basalt or basic metamorphic origin (Murtha *et al.* 1996).

The Cairns airport was formerly mangroves (RE 7.1.1) and saltpans (RE 7.1.2), and there were substantial areas of *Melaleuca leucadendra* forests (RE 7.2.8) at the base of Mount Whitfield. Open forests and woodlands dominated by *Eucalyptus leptophleba* were common north from this area. A wide belt of rainforest (REs 7.3.23a and 7.3.10a) with pockets of *Eucalyptus tereticornis* (7.3.12) clothed the levee of the Barron River.

North of here, a broken series of Pleistocene dunes usually supported mixed open forests of *Eucalyptus tereticornis*, *Corymbia tessellaris*, *Eucalyptus pellita*, *Corymbia intermedia*, *Melaleuca dealbata*, *Lophostemon suaveolens*, and *Acacia mangium* (vegetation community 7.2.4b). The dune swales supported stands of *Melaleuca leucadendra* (RE 7.2.8). The foredunes supported *Corymbia tessellaris* and *Corymbia clarksoniana* open forests (RE 7.2.3). A very old series of dunes west of the Moon River mangroves was apparently forested with vegetation types that are fairly atypical of dunes. These included a mesophyll vine forest of *Archontophoenix alexandrae* (vegetation community 7.2.1g), open forest of *Corymbia clarksoniana* (vegetation community 7.2.3g), and open woodland of *Corymbia clarksoniana*, *Eucalyptus platyphylla*, *Lophostemon suaveolens*, *Eucalyptus drepanophylla* and *Melaleuca viridiflora*. (vegetation community 7.2.11g).

The alluvial plains from the Barron River north to Buchan Point were dominated either by open forests of *Eucalyptus tereticornis*, with *Corymbia* spp. and *Lophostemon suaveolens* (RE 7.3.12) or of *Eucalyptus leptophleba* and *Corymbia clarksoniana* (RE 7.3.44). Creek levees were often marked by well-defined corridors of simple-complex semi-deciduous notophyll to mesophyll vine forest (RE 7.3.23). The narrow dune series north of Yorkeys Point was dominated by *Corymbia tessellaris* and *Corymbia* species open forest (RE 7.2.3) or by *Melaleuca leucadendra* open forest (RE 7.2.8) with occasional areas of vine scrub (REs 7.2.1 and 7.2.2)

Lowland pre-clearing vegetation: Daintree-Bloomfield/Macalister subregions

The most common and widespread vegetation group in the Daintree-Bloomfield/Macalister subregions was rainforest, which consisted of 5 regional ecosystems and covered 35% of the subregion (Table 8). Open forests were also very widespread (9 ecosystems, 20%), as were estuarine systems, which often dominated the relatively small lowland areas (4 ecosystems, 18 %) (Table 8). Much less extensive but still a prominent feature were dune eucalypt open forests (2 ecosystems, 5%), paperbark forests (3 ecosystems, 4%), dune vine scrubs (2 ecosystems, 3%), eucalypt woodlands (3 ecosystems, 3%), dune paperbark forests (3 ecosystems 3%) palm swamps (2 ecosystems, 2%), eucalypt open forests on low isolated hills (5 ecosystems 2%), tea-tree woodlands (1 ecosystem, 2 %), and rainforest on low isolated hills (2 ecosystems, 1%) (Table 8). A further 8 vegetation groups comprising 9 regional ecosystems covered the remaining 2% of the subregion (Table 8).

Open forests once dominated the floodplains from the small valley behind the Oak Beach/White Cliffs area, north to the Mossman River. These were mainly *Eucalyptus leptophleba* and *Corymbia clarksoniana* open forest (RE 7.3.44), or *Eucalyptus tereticornis* dominated open forests (RE 7.3.12). There were also small pockets of *Melaleuca viridiflora* woodland (RE 7.3.8), and *Melaleuca leucadendra* swamps (RE 7.3.25). Rainforest occurred on the more fertile areas such as the mesophyll vine forest (RE 7.3.10) of the Spring Creek Valley and on the better developed levees such as that of the Mowbray River which supported simple-complex semi-deciduous notophyll to mesophyll vine forest (RE 7.3.23). Dune systems in this area commonly included belts of dune vine scrub (RE 7.2.2a), especially at the Oak Beach/White Cliffs beach where this covered almost the entire dune. Also once extensive on the dune in this area were forests of *Corymbia tessellaris*, and *Corymbia clarksoniana* (or *Corymbia intermedia*) with areas dominated by *Acacia crassicarpa* (RE 7.2.3), and *Melaleuca leucadendra* (RE 7.2.8).

The township of Port Douglas was formerly largely a dune forest dominated by *Corymbia tessellaris*, and *C. clarksoniana* (and/or *C. intermedia*), with a long strip of vine forest (RE 7.2.2) along the foredune. The metamorphic outcrop and alluvial fan at Island Point (northern end of Port Douglas) was forested with *Eucalyptus leptophleba* and *Corymbia clarksoniana* (REs 7.11.49 and 7.3.44).

Table 8. Relative proportion of pre-clearing vegetation groups in the Daintree-Bloomfield subregion.

(The Daintree-Bloomfield subregion here includes small parts of the Macalister subregion. Vegetation groups occur on alluvium unless specified. "Open forest" and "woodland" here means eucalypt and *Lophostemon* dominated open forest and woodland respectively.)

Vegetation Group	No. of Regional Ecosystems	Area (ha)	% of Daintree-Bloomfield subregion
open forests	9	6 545	20
rainforest	5	11 280	35
estuarine	4	5 677	18
teatree	1	503	2
woodland	3	962	3
paperbark forests	3	1 381	4
grassland and sedgeland	1	2	<1
dune open forests	2	1 523	5
dune paperbark forests	3	831	3
palm swamps	2	720	2
open forests on hills	5	697	2
rainforest on hills	2	375	1
stream beds	1	275	<1
dune rainforests vinescrubs	2	1 074	3
woodland on hills	1	50	<1
casuarina	0	0	0
dune casuarina	1	170	1
acacia	1	186	1
dune shrublands and heathlands	0	0	0
fernland	1	3	<1
teatree on hills	0	0	0
shrubland on hills	2	20	<1
acacia on hills	0	0	0
grassland and sedgeland on hills	1	3	<1
TOTAL		**32 278**	**100**

Further north, the Cassowary Creek valley and Little (south) Mossman River valley were largely mesophyll vine forest (RE 7.3.10) with simple-complex semi-deciduous notophyll to mesophyll vine forest along the more fertile levees (RE 7.3.23). A few large pockets of *Eucalyptus tereticornis* dominated open forests (RE 7.3.12) occurred on the central and lower plains, whilst upper fans sometimes supported *Eucalyptus pellita* and *Corymbia intermedia* open forests (RE 7.3.20). The township of Mossman was once a *Eucalyptus tereticornis* dominated open forest (RE 7.3.12), and the main levee of the Mossman River valley was dominated by either simple-complex semi-deciduous notophyll to mesophyll vine forest (7.3.23) or complex mesophyll vine forest (7.3.17), with broad stretches of mesophyll vine forest (RE 7.3.10) across the rest of the floodplain. Some pockets of eucalypt open forest occurred on fans adjacent to the ranges (REs 7.3.19 and 7.3.20).

The stretch of lowlands from the rainforests of the Mossman River levee to those of the Saltwater Creek/Whyanbeel Creek area were largely dominated by swampy sclerophyll communities. These included *Eucalyptus pellita* and *Corymbia intermedia* open forests (RE 7.3.7), stands of *Melaleuca quinquenervia* (RE 7.3.5), and woodlands/open forests of *Melaleuca viridiflora* and *Lophostemon suaveolens* (RE 7.3.8). There were also some *Eucalyptus tereticornis* dominated communities (RE 7.3.12) and *Archontophoenix alexandrae* swamps (RE 7.3.3). The Saltwater Creek/ Whyanbeel Creek valleys were entirely rainforested with mesophyll vine forest (RE 7.3.10) and some simple-complex semi-deciduous notophyll to mesophyll vine forest (RE 7.3.23) along the levees.

The stretch of dunes from north of Port Douglas to the mouth of the Daintree River once supported a sizeable area of dune vine scrub (RE 7.2.2) including the dune north of the mouth of Saltwater Creek where vine scrub appears to have clothed almost the entire dune system. Similarly the large dune system at Wonga (south of the mouth of the Daintree River) appears also to have mainly consisted of vine scrubs (RE 7.2.2). Figure 9 shows dune vine scrub portrayed on an original surveyors' plan from Palm Beach (a few km north-east of Mossman). The sizeable dune systems either side of the Mossman River were probably mostly vegetated with *Corymbia intermedia* and *Eucalyptus pellita* open forests (RE 7.2.4). The more inland dunes upstream of the mouth of the Daintree River supported a complex variety of sclerophyll associations including *Corymbia intermedia* and *Acacia crassicarpa* open forests (RE 7.2.3), *Melaleuca viridiflora*, and *Lophostemon suaveolens* open forests (RE 7.2.11), shrublands of *Melaleuca quinquenervia* (RE 7.2.9) and open forests of *Corymbia intermedia* and *Eucalyptus pellita* (RE 7.2.4).

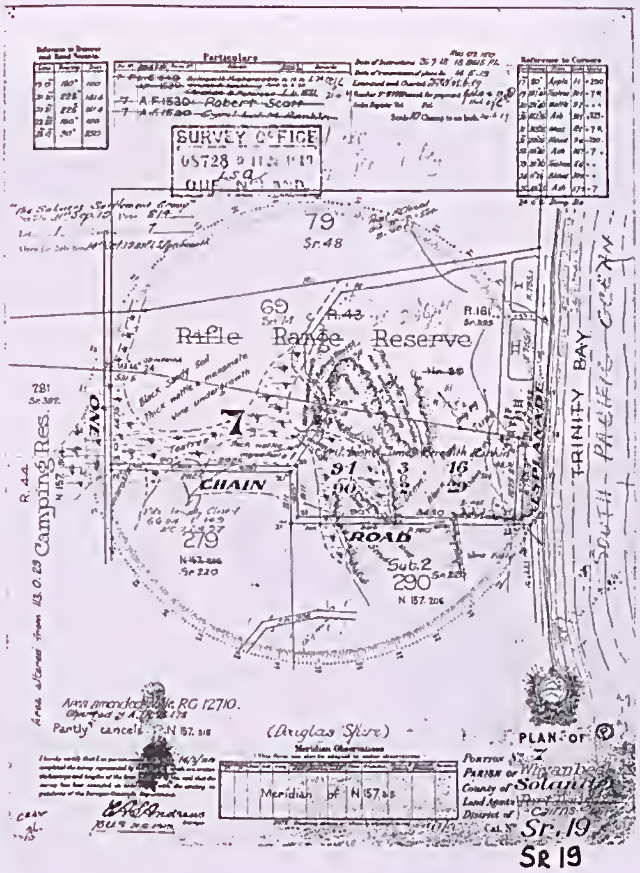

Fig. 9. Original survey plan of Palm Beach/Newell (Trinity Bay). The plans were repeatedly revised as years passed and the land was subdivided, sometimes obscuring the original annotations and text. Despite alterations this plan clearly demarks areas of *dense vine scrub, black sandy soil, thick wattle and messmate vine undergrowth* and a *tea tree* swamp (with swamp symbols).

Alluvium surrounding the mouth of the Daintree River was a complex of rainforests and swampy rainforest and sclerophyll communities. These included complex mesophyll vine forest (RE 7.3.10), extensive *Licuala ramsayi* forests (RE 7.3.4) and *Archontophoenix alexandrae* forests (RE 7.3.3), *Melaleuca quinquenervia* swamps (RE 7.3.5), and open forests of *Eucalyptus pellita* and *Corymbia intermedia* RE 7.3.7). The swampy oxbow of Bailey Creek (immediately south of the Daintree River crossing) supported stands of *Melaleuca cajaputi* (vegetation community 7.3.5c), which appears to have always been rare in the Wet Tropics.

The upper Daintree River/Douglas Creek/Stuart Creek valleys were entirely rainforest, mainly simple-complex semi-deciduous notophyll to mesophyll vine forest (RE 7.3.23) and mesophyll vine forest (RE 7.3.10).

The Hutchinson Creek valley (behind Alexandra Bay) was very complex mosaic of swampy rainforest and sclerophyll communities including swampier forms of mesophyll rainforest (RE 7.3.10), large *Licuala ramsayi* swamps (RE 7.3.4), *Melaleuca leucadendra* open forests (RE 7.3.25), *Eucalyptus pellita* and *Corymbia intermedia* pen forests (RE 7.3.7), and *Eucalyptus tereticornis* open forest (RE 7.3.40). Adjacent to the mangroves there were also pockets of *Melaleuca viridiflora* (RE 7.3.8) and swamps of *Melaleuca quinquenervia* (RE 7.3.5). The better drained alluvial fans on the western edge of the valley tended to support complex mesophyll vine forest (RE 7.3.17).

The Myall Creek/Mason Creek valley at Cape Tribulation appears to have been almost entirely complex mesophyll vine forest (RE 7.3.17) apart from the *Melaleuca leucadendra* dominated dune system (RE 7.2.8) that still remains today.

Most of the small alluvial valleys north of Cape Tribulation still remain vegetated today, and tend to become gradually more dominated by sclerophyll vegetation further north as annual rainfall decreases. Sclerophyll communities include *Corymbia intermedia*, and *Eucalyptus pellita* on alluvial fans (RE 7.3.20), *Corymbia tessellaris* and *Corymbia intermedia* open forest (RE 7.3.19), and *Corymbia clarksoniana* open forests and woodlands (RE 7.3.45). From the Wujal Wujal/ Wyalla Plain area *Corymbia nesophila* open forest to woodland (RE 7.3.13) becomes common. Rainforest vegetation tends to be restricted to levees and is either mesophyll vine forest (7.3.10) or simple-complex semi-deciduous notophyll to mesophyll vine forest (7.3.23a). Dunes are often dominated by vine scrub (REs 7.2.1 and 7.2.2), with some areas of *Corymbia tessellaris* and *Corymbia clarksoniana* open forest and *Melaleuca leucadendra* open forest (RE 7.2.8).

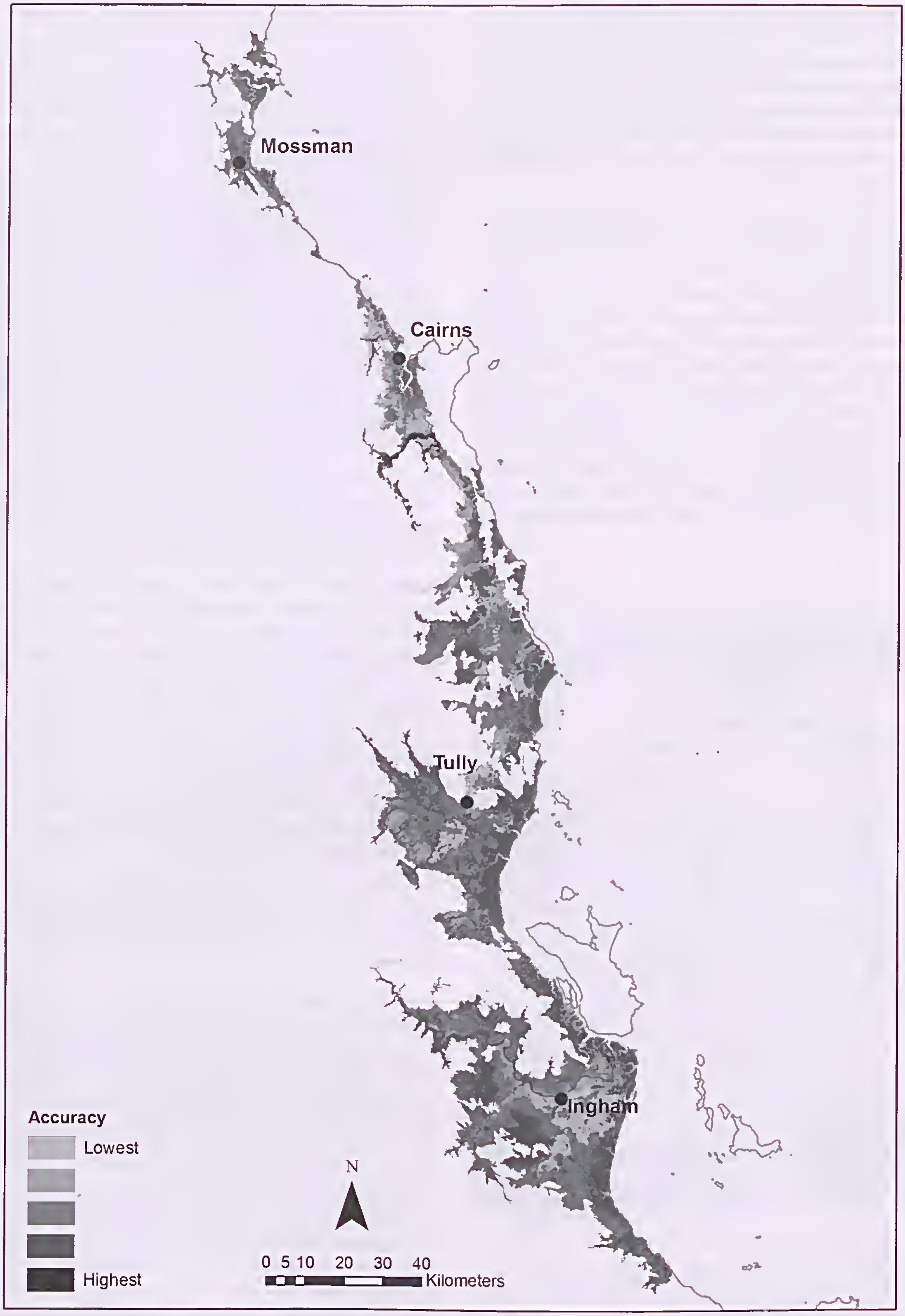

Fig. 10. Accuracy or confidence of pre-clearing mapping across the study area. Darker areas indicate higher confidence (and often indicate areas of remnant vegetation), whilst lighter areas represent least confidence.

Confidence in accuracy of the pre-clearing mapping

The relative confidence in accuracy across the pre-clearing area is shown in Figure 10. As a general rule, those areas that were first settled and cultivated by Europeans show the least confidence, such as the lower Herbert, Tully, Innisfail and back-plains of Cairns. Some of the areas with the lowest confidence were those where several interpretations of surveyors' plans were possible. For instance the authors believe that the majority of the grassy plains illustrated on the plans, were genuine grasslands. However it is quite feasible that some were not. The grasslands and open forests in areas that were settled and cultivated very early, were often substantially modified before the surveyors arrived. Although the surveyors' plans often described them as *plains*, it is possible that some of these *plains* may have previously (or even during the surveyors' times) been populated with eucalypts. Lumholtz (1889) describes the lower Herbert; *The banks of the river consist of rich soil, and on the higher ground are extensive plains covered with mighty gum-trees, which were continually being felled...*, He also mentions gliding possums (genus *Petaurus*) which live in trees; "*..but I found Petauroides volans and several species of Petaurus in the middle of summer on the open grass plains in the mountain regions near Herbert Vale.*

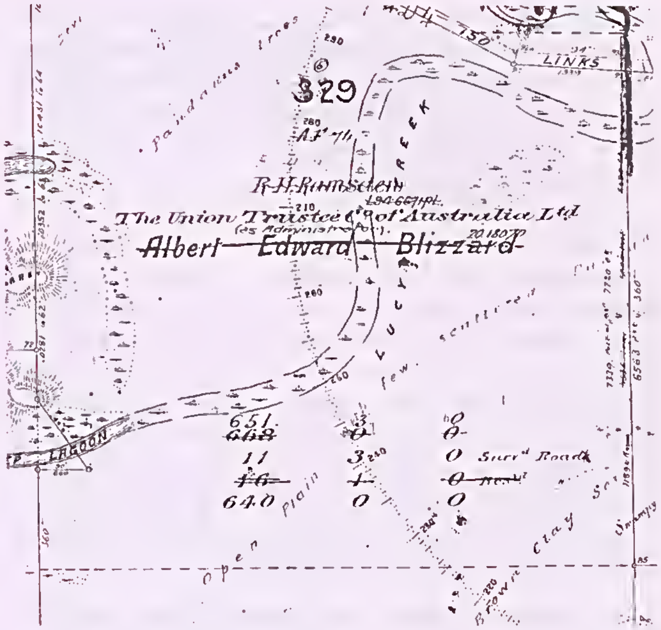

Fig. 11. Original 1885 survey plan from the Lucy Creek (central-eastern Herbert River floodplain) area showing references to plains.

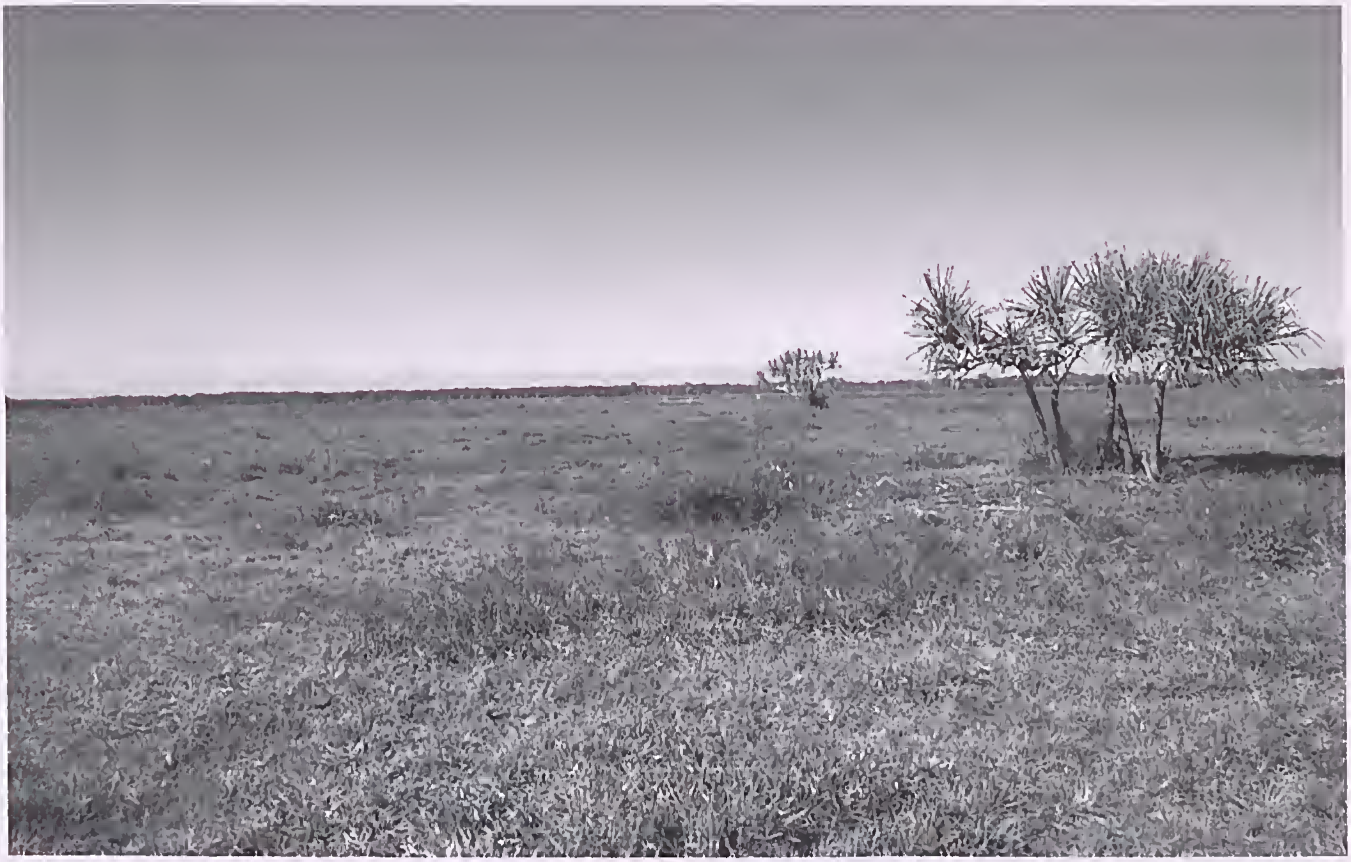

Fig. 12. 2003 photograph of plains between Ingham and Forrest beach (same general area as Figure 10), believed to have been formerly treeless, and similar to today in appearance. However it would have probably been less heavily grazed, with different grass species composition. The foreground area is classed as "cleared" vegetation in the mapping coverage due to the almost complete replacement of native grasses with introduced pasture grasses.

On the lower Herbert floodplain east of Ingham the land was developed for sugarcane around the late 1860s. Aerial photos from 1942 show extensive grasslands in this area, including some areas that were obviously a result of clearing of timber. Surveyors' plans in the area date from 1872 to 1885 and use the terms *open plain*, *swampy open plain*, and *open plain with occasional clumps of pandanus* (Figure 11, Figure 12). The surveyors' plans have in other areas also used the terms *cleared land* or *land under cultivation*. Although it is possible that some of the *open plains* had been previously cleared, it seems unlikely that the surveyors would not know this, as there was probably not enough time for the stumps to have rotted away between the period of first development (late 1860s) and the surveyors' plans (1872–85). On weighing this evidence, in particular the short time period between first settlement and date of the surveyors' plans, the most likely conclusion is that the majority of the *plains* depicted were natural open grasslands and swamps.

Low confidence ratings were assigned to some vegetation types that are difficult to map even with good aerial photography, and to a few vegetation communities that are virtually extinct today (uncertainty surrounding their species composition and structure means that their boundaries are difficult to define).

Improvements in mapping

The 1:80 000 scale aerial photographs (1960–61) proved to be the most time-effective method of creating the pre-clearing coverage (older photos were only used for areas showing as cleared on these). Examination of older aerial photos (where available) for these vegetated areas would be of value, where they provide a larger scale and better detail. Complementary use of surveyors' plans for areas vegetated on these photos may be useful. Actual registration of the plans to match the pre-clearing coverage may consume equivalent time to the method used in this project, and would be of greater use (since the original information could be displayed directly under the pre-clearing layer).

More detailed field checking would be very valuable, as small remnant stands or isolated trees (too small to map by Stanton and Stanton 2005) would provide valuable clues as to the original vegetation. Also landforms and soils observed directly in the field can be used as evidence for the existence of particular vegetation types.

Finally some of the vegetation communities mapped on the lowlands could be further improved in definition. In particular the RE 7.3.12 (*Eucalyptus tereticornis* open forests with mixtures of other species) is very broad in definition and occurs on a wide variety of landforms. Re-classification of this RE may be beneficial. Similarly the REs 7.3.16 (*Eucalyptus platyphylla* woodlands and open forests with mixtures of other species and includes densely forested types on levees as well as open woodlands on hard-setting clay plains) could be further divided. In addition the RE 7.3.8 (broad-leaf tea-tree woodlands) may benefit from division based on soil and understorey vegetation characteristics.

Table 9. Comparison of CSIRO coverage (Johnson et al. 2000) with this study.

The vegetation communities of this study grouped to match those of Johnson et al. (2000). Figures are derived only from the area that is common to both coverages. The "Area mapped by either coverage (B)" is calculated from an intersection of the two coverages. It is equivalent to: area mapped only in one coverage + area mapped only in the other coverage + area mapped by both coverages.

Vegetation category	Area (ha) mapped in CSIRO coverage	Area (ha) mapped in this study	% area mapped in CSIRO coverage	% area mapped in this study	Area (ha) mapped where both coverages agree (A)	Area (ha) mapped by either coverage (B)	% similarity per vegetation category (A/B X100)
mp (mangrove patterns)	14 426	13 499	9	8	12 226	15 700	**78**
edp (eucalypt dominated patterns)	65 085	88 528	39	53	50 506	103 107	**49**
bv (beach vegetation)	1 803	3 131	1	2	1 362	3 573	**38**
uss (unstable silt and sand)	848	1 338	<1	<1	576	1 610	**36**
gs (grasslands)	19 505	23 887	12	14	10 055	33 337	**30**
rp (rainforest patterns)	22 678	8 784	14	5	6 434	25 028	**26**
mdp (melaleuca dominated patterns)	42 706	27 800	25	17	11 185	59 301	**19**
ow (open water)	731	835	<1	<1	183	1 383	**0**
Total	**167 783**	**167 783**	**100**	**100**			

Table 10. Percent remaining area for each regional ecosystem (RE) which occurs in the lowlands of the Wet Tropics (figures are for the entire Wet Tropics bioregion).

REs which occur on hills (or for which the majority occurs outside the lowlands) have been excluded. Vegetation Management Status and Biodiversity Status have been obtained from the coverage of Queensland Herbarium and Wet Tropics Management Authority (2005), and an explanation of their derivation can be found in Environmental Protection Agency (2005). Ecosystems with greater than 100% remaining have increased in area due to natural environmental changes or indirect changes caused by European-man landscape modification.

Regional Ecosystem	Pre-clear area (ha)	Remnant 2003 area (ha)	Percent remaining	Vegetation Management Status	Biodiversity Status
7.1.1	47 220	44 951	95	N	N
7.1.2	6 443	4 849	75	O	O
7.1.3	1 572	1 899	121	O	E
7.1.4	243	224	92	O	E
7.1.5	328	348	106	O	O
7.2.1	2 541	589	23	E	E
7.2.2	1 097	552	50	O	E
7.2.3	11 682	7 036	60	O	O
7.2.4	5 548	2 748	50	O	O
7.2.5	552	376	68	O	O
7.2.6	299	299	100	O	O
7.2.7	1 325	965	73	O	E
7.2.8	2 384	1 578	66	O	E
7.2.9	3 672	2 839	77	O	E
7.2.10	504	504	100	O	O
7.2.11	2 523	1 468	58	O	O
7.3.1	13 454	1 262	9	E	E
7.3.3	4 648	1 823	39	O	E
7.3.4	2 814	1 103	39	O	E
7.3.5	25 315	11 389	45	N	E
7.3.6	2 419	678	28	E	E
7.3.7	8 897	1 236	14	E	E
7.3.8	38 987	15 887	41	N	E
7.3.9	11 000	1 180	11	E	E
7.3.10	59 371	13 949	24	O	E
7.3.12	26 130	4 491	17	E	E
7.3.13	994	691	70	O	E
7.3.16	37 485	16 560	44	N	E
7.3.17	26 370	3 907	15	E	E
7.3.19	6 413	4 210	66	O	O
7.3.20	10 504	6 079	58	O	O
7.3.21	5 966	4 037	68	O	O
7.3.23	15 524	3 622	23	E	E
7.3.25	8 287	5 020	61	O	O
7.3.26	4 084	3 782	93	O	E
7.3.28	7 393	7 291	99	O	E
7.3.29	2 047	846	41	O	E
7.3.30	462	36	8	E	E
7.3.31	625	535	86	O	E
7.3.32	12 299	115	<1	E	E
7.3.34	2 222	462	21	E	E
7.3.35	1 131	279	25	E	E
7.3.36	1 186	435	37	O	E
7.3.38	200	198	99	O	O
7.3.40	15 696	4 045	26	E	E
7.3.43	3 022	2 331	77	O	E
7.3.44	2 456	597	24	E	E
7.3.45	33 852	12 180	36	N	O
7.3.46	7 593	1 729	23	E	E
7.3.47	114	114	100	O	O
7.3.49	787	793	101	O	O
7.3.50	487	452	93	O	E
7.8.1	30 675	10 776	35	N	E
7.8.2	51 907	21 451	42	N	O
7.8.7	1 304	952	73	O	E
7.8.11	553	553	100	O	O
7.8.12	319	319	100	O	E
7.8.14	899	526	59	O	E
7.8.18	925	385	42	O	O
7.8.19	8 345	1 851	22	E	E

Comparison with previous pre-clearing vegetation coverages

The broad vegetation classes in the Herbert subregion lowlands from this project were compared with the Johnson *et al.* (2000) pre-European mapping (Table 9). Mangrove patterns showed the highest degree of similarity (78%), whilst other vegetation patterns showed considerably less correspondence, with *Melaleuca*-dominated patterns very dissimilar (19%); even rainforest showed a low correlation (26%). This fairly poor correlation is despite the fact that the data sources used were similar (eg. oldest aerial photography and soils mapping). The use of old land survey plan information for the current project is most likely the reason for differences in areas mapped as grassland in the lower Palm Creek/Lucy Creek floodplain. These areas were cleared prior to the oldest aerial photography, and where Johnson *et al.* (2000) has relied on soils mapping to predict vegetation distribution, this study has used the old land survey plans for grassland and rainforest boundaries. Both methods are valid, and neither method is 100% reliable, though the authors believe that overall, the contribution of the surveyors' plans have led to a more accurate result.

Similarly, differences between the two projects in the central Herbert River levee and the Lucy Creek levee (and associated prior streams) are largely the result of the use of old land survey plan information for the current project. Both these levees were almost completely cleared on the oldest aerial photography (1942). The soil types mapped (Wilson and Baker 1990) appear to be suitable for rainforest vegetation, however old land survey plans describe various plains and pandanus clumps (Figure 11).

Surprisingly even rainforest appears to correlate poorly between the two projects. However this is most likely explained by the differences in the interpretation of "rainforest". Regional ecosystems considered to be rainforest in the current project generally do not contain emergents or an overstorey of sclerophyll species. Thus much vegetation with a well-developed rainforest component but a paperbark or eucalypt overstorey is classified into sclerophyll REs. These REs usually have very dark photo-patterns similar to rainforest and have probably been interpreted as rainforest by Johnson *et al*. (2000).

The vegetation type with the least correlation was "melaleuca dominated patterns". This is not surprising given that they were mapped over much of the area classified as grassland in the current project. In addition, the regional ecosystem 7.3.9, (which was classed into "eucalyptus dominated patterns" for this comparison), may have been interpreted as a "melaleuca dominated pattern" by Johnson *et al*. (2000) due its very dense nature, and the common presence of *Melaleuca dealbata*.

We are unable to provide a satisfactory comparison with Accad (2003) at this stage. Both projects used similar baseline data (Stanton & Stanton 2005), but Accad's work was based on a very early draft of the latter, and the Stanton and Stanton (2005) coverage had changed considerably by the time it was used for this project.

Evidence of vegetation manipulation by indigenous inhabitants

Direct evidence of indigenous people changing their environment is found in references to open ceremonial or camping areas referred to as *borboby*, *prun* or *brun* sites (local terms for *bora ground*) (Horsfall 1987). Their construction and/or maintenance are mentioned in Palmerston (1885–1886), Palmerston (1887), Mjöberg (1918), and Horsfall (1987). Some of these may have been of a size possible to map at the scale used for this project (e.g. *about 3 acres* Douglas (1882), and plate 3.2 in Mjöberg 1918), though it is possible that these largest examples were enlarged by Europeans. Research into the location of *borboby*, *prun* or *brun* sites would be a valuable addition to the map coverage. Information could come from historical compilations, old forestry maps, original explorers' manuscripts and interviews with experts, key indigenous elders and farmers who have had a long association with their local area.

Indirect evidence of the impact of indigenous people on vegetation structure is provided by the apparent occurrence, in pre-clearing times, of grasslands on very fertile, well-drained soils (including Herbert, Lucy and Palm soil types – Wilson & Baker 1990) which, in other parts of the pre-clearing map, support rainforest or eucalypt open forest. From the central Herbert River floodplain G. E. Dalrymple (Dalrymple 1865) reported *extensive rolling plains, with grasses as high as my saddle-bow, but by no means coarse, and the richest red chocolate covered loam I have seen in Queensland*. Assuming that his horse was of a reasonable stature, the possible native grass candidates (which still occur on the better soils in the general area) are *Imperata cylindrica*, *Heteropogon triticeus*, *Sarga* spp., *Sorghum nitidum* forma *aristatum* and *Mnesithea rottboelloides*. *Imperata cylindrica* tends to be somewhat "coarse" in nature, and favours more moderately to poorly-drained soils. The other three candidates will not tolerate swampy conditions and are indicative of relatively good soils. It is extremely rare today to find grasslands composed of these species in the wet tropics. However similar country in the Central Queensland Coast, the Goorganga plains near Proserpine, does support an occurrence of several hectares of tall dense *Sorghum nitidum* grassland. This plain is being invaded by trees of *Corymbia tessellaris* (Kemp *et al.* 2001) ; perhaps reverting to a forested state due to lack of burning.

We noted considerable reduction in grassland area in parts of the Herbert valley (comparing 1940s and 1960s aerial photos – though these changes were not incorporated into the mapping, as the 1960s photos were generally used to create the vegetation coverage for areas considered to be uncleared at that time). Possible explanations for reduction in natural grasslands include cessation of regular burning, changes to landscape drainage, or perhaps increasing CO_2 in the atmosphere.

It is clear that there were large numbers of people living in the lowlands wet tropics in pre-clearing times. The construction of bora grounds caused obvious small-scale vegetation structural change, but the extent to which country was kept open through burning requires further investigation, perhaps through analysis of soil type in relation to the pre-clearing mapping. Careful studies of sequences of aerial photos for particular areas may reveal changes over time, which could be linked to the cessation of regular burning.

Conservation value of vegetation communities and regional ecosystems

Some of the vegetation communities and regional ecosystems of the Coastal lowlands were formerly extensive but have now been dramatically reduced in area (Table 10). Those which have been cleared to the greatest extent include the three grassland ecosystems (RE 7.3.32, 1% remaining; RE 7.3.30, 8% remaining; and RE 7.3.1 9% remaining), *Corymbia tessellaris* forests with *Acacia* spp., *Melaleuca* spp. and *Lophostemon suaveolens* (RE 7.3.9, 11% remaining), *Eucalyptus pellita* and *Corymbia* spp. forests (RE 7.3.7, 14% remaining), and *Eucalyptus tereticornis* (often mixed with other species) forests (RE 7.3.12, 17% remaining). The least impacted ecosystems are those occurring on marine sediments (eg REs 7.1.1, 7.1.3, 7.1.4 and 7.1.5), some of the near-coastal REs (eg 7.2.6, 7.2.10, 7.3.31 and 7.3.47), REs occurring in narrow bands along creek banks or creek beds (eg 7.3.26, 7.3.28, 7.3.49 and 7.3.50), or REs of very restricted occurrence (eg 7.3.38, 7.8.11 and 7.8.12) (Table 10 and Maps 1–4).

The formerly most extensive grassland REs 7.3.1a and 7.3.1b appear to have been heavily impacted with only 13% and 8% remaining respectively (Table 11) though the relatively poorly-drained plains (Table 4 and Wilson & Baker 1990) which supported 7.3.1c still retains 93% of pre-clearing extent.

The RE 7.3.32 has been even more severely impacted, occurring on better-drained soils (Table 4 and Wilson & Baker 1990), with the dominant vegetation community (7.3.32a) virtually extinct at 1% remaining (Table 11). The vegetation community 7.3.32b remains intact (Table 11) but is naturally very rare. These figures are likely to be an overestimate of the status of communities as many remnant patches of vegetation have been severely invaded by weeds (particularly 7.3.1c which is heavily invaded by the exotic grass *Urochloa mutica*. It was not possible to eliminate severely-impacted remnants using the predominantly remote methods utilised by this study.

The *Corymbia tessellaris* forests with *Acacia* spp., *Melaleuca* spp. and *Lophostemon suaveolens* once covered river and creek levees, particularly the fertile levees of the Herbert River and other minor creeks on the Herbert floodplain. These were obviously targeted early for clearing due to ease of access and the moderate to relatively high-yield soils (Wilson & Baker 1990), (most commonly Toobanna (Tb), Palm (Pl) and Herbert (Hb) series (Table 4). It is probably this regional ecosystem (or possibly RE 7.3.12) being referred to by Lumholtz (1889) where he describes the lower Herbert thus; *The banks of the river consist of rich soil, and on the higher ground are extensive plains covered with mighty gum-trees, which were continually being felled...*

Though often occurring on relatively swampy soils, (eg. Bulgun (Bg) Table 4 and Canon *et al.* 1992), the *Corymbia* spp. and *Eucalyptus pellita* forests (RE 7.3.7) have also now been largely cleared (Table 10). The *Eucalyptus tereticornis* open forest and woodlands (RE 7.3.12), which mostly occurred on fairly well-drained, arable soils (Table 4, also Canon *et al.* 1992, Murtha 1986, Murtha 1989, Murtha *et al.* 1996, and Wilson and Baker, 1990) have also been severely depleted (Table 10). Of the three component vegetation communities, all are heavily impacted, and one (7.3.12c) is virtually extinct (Table 11). Although remnants of 7.3.12c occur (Maps 1–4), their structure and composition has changed considerably due to logging and rainforest invasion. All remaining fragments require field verification.

Rainforests have also been severely depleted, with the dominant REs (7.3.10, 7.3.17, 7.3.23, and 7.8.1) being cleared to low levels (Table 10). These REs sometimes also occur in upland areas, and when only the lowlands are considered, they have been reduced to a very minimal extent (RE 7.3.10 = 11%, 7.3.17 = 15%, 7.3.23 = 3% and 7.8.1 = 5%). These ecosystems often occurred on the very best soil types with REs 7.3.10, 7.3.17 and 7.3.23 frequently occurring on Tully (Tu), Coom (Co), Liverpool (Li) and Macknade (Mk) (Table 4 and Wilson and Baker 1992). Although Coom is a poorly drained soil types, the others are well-drained, deep fertile soils (Wilson and Baker 1992). The RE 7.8.1 occurs predominantly on the basalt soil series Pin Gin (Pg) (Table 4 and Murtha *et al.* 1996) which are red gradational soils, derived from basalt (Murtha *et al.* 1996).

Discussion

Coastal lowlands pre-clearing vegetation communities and regional ecosystems

Rainforests covered around 24% of the Wet Tropics coastal lowlands in pre-clearing times – fitting with the wet, green image of the Wet Tropics. Eucalypt forests dominated overall, with woodlands and open forests together covering some 32% of the lowlands. Estuarine systems, paperbark and tea-tree forests, and grasslands were also very prominent (11%). The total area of coastal lowland vegetation remaining today ranges from 37% of Herbert subregion down to 24% of Innisfail (Table 12). Overall about two-thirds of the native vegetation has been cleared.

The Herbert subregion, the driest of the lowland subregions, supported the least rainforest. Possibly the most intriguing of vegetation patterns in the Herbert are the now near-extinct grasslands which dominated the central and lower floodplain, covering a very large area (12% of the Herbert subregion lowlands). Soil type appears to be a reasonable predictor of some of the grassland vegetation communities (e.g. *Cynodon dactylon* grassland (7.3.1b) corresponds well with soil series Hl (Hamleigh) (Table 4, Wilson and Baker 1990)), however grasslands also seem to have occurred on better-drained soil types, which often also supported timbered vegetation in other areas.

The Tully subregion was perhaps once the most stunning subregions visually, with its diverse and complex patterns of tea tree and paperbark communities, eucalypt forests, palm forests and rainforest. These complex patterns are reflected in the soils mapping (Canon *et al.* 1992) and may be a result of constant re-working of materials by the changing river and creek systems across the floodplain. The vegetation type 7.3.12c with its widely spaced forest red gums and mid-stratum of tea-trees is virtually extinct now. The few patches that remain warrant field investigation to obtain further information regarding their composition, and to quantify the degree of rainforest invasion.

The Innisfail subregion supported the broadest expanses of rainforest, partly due to the high rainfall, but also due to the extensive areas of gently-sloping basalt terrain, the majority of which supported distinct rainforest types (complex mesophyll vine forest; 7.8.1a, and complex mesophyll vine forest on laterite; 7.8.1b). Almost the entire Palmerston area to Innisfail was covered in lowland rainforest, some 20 000 hectares in all. When palm swamps are included, the upper El Arish/Silkwood/Japoonvale valley, the central and upper

Table 11. Percent remaining area for selected vegetation communities in the coastal lowlands of the Wet Tropics

Vegetation Management Status and Biodiversity Status from Queensland Herbarium and Wet Tropics Management Authority (2005)- their derivation is in Environmental Protection Agency (2005).

Vegetation community	Description	Pre-clear area (ha)	Remnant 2003 area (ha)	Percent remaining	Vegetation Management status	Bio diversity status
7.3.1a	*Hemarthria uncinata* and/or *Ischaemum australe* subsp. *arundinaceum* closed grassland.	1 693	223	13	E	E
7.3.1b	*Cynodon dactylon* grassland	11 693	976	8	E	E
7.3.1c	Ephemeral freshwater swamp dominated by sedges	68	63	93	E	E
7.3.12a	*Eucalyptus tereticornis, Corymbia tessellaris, E. pellita, C. intermedia, Melaleuca dealbata* and *Lophostemon suaveolens* woodland to open forest, often with a secondary tree layer of *Acacia mangium* and *A. crassicarpa.*	11 740	1 542	13	E	E
7.3.12b	*Eucalyptus tereticornis, Corymbia tessellaris, E. pellita, C. intermedia, Melaleuca dealbata* and *Lophostemon suaveolens* woodland to open forest, often with a secondary tree layer of *Acacia mangium* and *A. crassicarpa*, and with a very well developed vine forest understorey.	7 362	2 550	35	E	E
7.3.12c	*Eucalyptus tereticornis* open woodland to sparse woodland over a prominent secondary tree layer of *Melaleuca quinquenervia* and/or *M. viridiflora.*	7 028	399	6	E	E
7.3.32a	*Imperata cylindrica* and/or *Sorghum nitidum* and/or *Mnesithea rottboellioides* closed grassland.	12 276	92	1	E	E
7.3.32b	Grassland dominated by *Themeda triandra.*	23	23	100	E	E

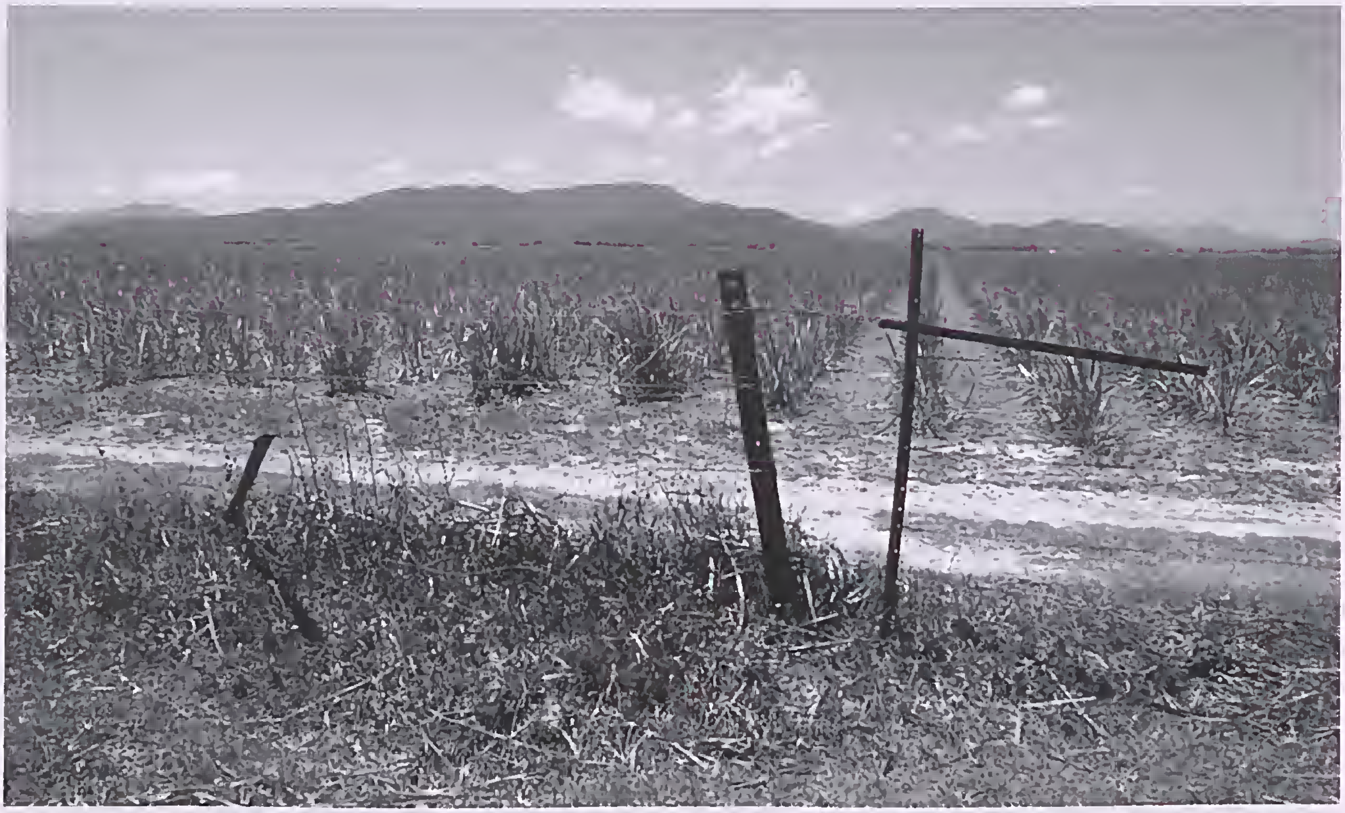

Fig. 12. Scene across the Herbert lowlands in 2003, between Trebonne and Ingham (north from Wharps Holding). The Mount Leach Range and Hinchinbrook Island are in the background. In pre-clearing times the view would have been almost as open, with native grass plains and sedge swamps (REs 7.3.32 and 7.3.1) through to the Herbert River (dark trees at base of mountains).

Russell River Valley, the upper Babinda Creek valley, the entire lowland stretch from Babinda to Meerawa, the central and upper Mulgrave valley and the Freshwater Creek valley south of Redlynch were also completely covered with rainforest.

The flat plain south of Trinity Inlet (the Mulgrave Corridor) is fascinating due to its once apparently very low dense sclerophyll vegetation in pre-clearing times reflected both on the 1942 aerial photography, and the old land survey plans which have abundant reference to dense forest with a thick undergowth (eg. *thickly timbered with mahogany tea tree gum and wattle, poor grey soil, thick growth of saplings*). This is reminiscent of regrowth vegetation from a broad-scale clearing event or other similarly high-disturbance episode. Though it is possible that this area was completely cleared before the 1940s, it seems more likely that such clearing efforts would have concentrated on vegetation of the more fertile soils. It is probable that the Mulgrave River formerly flowed northwards out to sea in this area, and was later diverted southwards, possibly due to the formation of the Mulgrave fan (Willmott & Stephenson 1989). Sea levels in this area around 5500 years ago were approximately 1m higher than today (Chappell *et al*., 1983), suggesting that this low-lying area may once have been mangroves. This vegetation type (7.3.45f) was mostly associated with the "Inlet" (Il) soil series (Table 4). Murtha *et al*. (1996) describe this soil type as being of "possible marine origin", and that it overlies marine sediments. It therefore seems possible that this area was once a broad mangrove system, and that the low dense vegetation may represent a recent colonisation by non-marine vegetation.

The Cairns city area is built on a low, complex dune system. The long narrow swales extending roughly north-south across the entire length of the city supported mangroves, or paperbark forests which received some tidal influence, or else were at least connected to the saline areas and ultimately the ocean. In short, most of Cairns city could easily be inundated by the sea, via a storm surge or sea level rise. This beach ridge system was likely formed through a series of relatively recent cyclones (as far back as about 6000 years ago) (Nott, 2003).

One of the outstanding features of the Daintree-Bloomfield/ Macalister lowlands was the occurrence of large continuous vine scrubs (or "beach scrubs") on dunes, particularly notophyll vine forest (7.2.2) (the original Tracey (1975) type 7b). This ecosystem is less common in other subregions, tending to be replaced by the more mesic mesophyll vine forest in the Innisfail subregion (7.2.1). In the southern, drier subregions beach scrubs tend towards notophyll vine forest but are usually dominated by the related ecosystem mesophyll/notophyll vine forest of *Syzgium forte* subsp. *forte* (7.2.5), and are far less extensive.

Broad rainforest belts and large palm swamps were also a feature of this subregion, but with lower rainfall than that of the Innisfail subregion, there were also extensive open forests, including those of *Corymbia nesophila* which is not found in any other coastal subregion and is a species more typical of the Cape York Peninsula bioregion.

Table 12. Area of coastal lowlands alluvial and dune vegetation remaining by subregion

Note: area figures exclude estuarine systems and low isolated hills.

Subregion	Percent vegetation remaining
Daintree and Macalistair lowlands	36%
Herbert lowlands	37%
Innisfail lowlands	24%
Tully lowlands	35%

Conservation value of vegetation communities and regional ecosystems

The Queensland Government has assigned a Vegetation Management Status to each regional ecosystem in the State, which is supported by legislation (the Vegetation Management Act 1999 and Vegetation Management Regulation 2000). This status is based solely on the percent of pre-clearing area remaining at a bioregional level, as well as particular remnant area thresholds. The pre-clearing mapping for the Wet Tropics produced through the current project was used to update this legislation (Vegetation Management Regulation 2000 Reprint No. 2J, 9 December 2005). In addition to this legislated conservation status, the Queensland Environmental Protection Agency has developed a "Biodiversity Status" for each regional ecosystem (Environmental Protection Agency, 2005), which is based on an assessment of the condition of remnant vegetation in addition to the pre-clearing and remnant extent of the regional ecosystem. Thus for example an ecosystem which has greater than 70% of its area irreversibly invaded by weeds is moved to a more threatened status. This Biodiversity Status is used by a variety of government organisations (mainly the Environmental Protection Agency) and private organisations to guide development and conservation planning decisions.

A previous assessment equivalent to Biodiversity Status was made at the subregional level (and using the more detailed Vegetation Community classification level) for the Herbert and Tully subregions by Kemp *et al*. (1999) and Kemp and Morgan (1999), using estimations of pre-clearing area based on soil and land-systems mapping. However, no similar detailed examination at a subregional level has yet been undertaken using the new regional ecosystem mapping (Queensland Herbarium and Wet Tropics Management Authority 2005) which includes the pre-clearing work presented in this manuscript. This should be a priority for broad scale land managers, particularly as it may assist with identifying vegetation communities that are at the brink of local extinction, or which occur only on freehold land and are therefore at risk of degradation through farming, and gradual fragmentation (via clearing for roads and infrastructure).

The grassland and sedgeland communities have suffered great loss with *Imperata cylindrica* dominated grasslands at 1% of pre-clear extent, sedgeland/fernland complexes at 8%, and the swampier grass communities at 9% (Figure 12). From the authors' field experience it is clear that most remaining examples are severely impacted by weed invasion and species changes due to cattle grazing and the introduction of pasture species. For example, the grasslands in Wharps and Lannercost Holding, are today dominated by *Cynodon dactylon*, *Chrysopogon aciculatus*, and *Mimosa pudica*. It seems probable that grazing has favoured the resilient *Cynodon dactylon* at the expensive of more sensitive tussock grasses such as *Ischaemum* species, *Sorghum nitidum* forma *aristatum* and *Sarga* spp. The naturalised species *Cynodon dactylon* has probably become dominant as a result of grazing. Whilst some other native sedges and grasses, and other herbaceous plants still occur in these grasslands, they occur in very low abundance.

The grasslands of Eubenangee swamp are mostly *Hemarthria uncinata* and/or *Ischaemum australe* subsp. *arundinaceum* closed grassland. The current condition of these grasslands is excellent. This area is an example of a lowland swamp complex that is extremely unusual in that it remains barely affected by ponded pasture species and other pasture grasses, or even the invasive *Annona glabra*. This is entirely due to the dedicated efforts of Queensland Parks and Wildlife Service rangers and senior staff in charge of the area.

A few grasslands remain on better-drained soils (*Imperata cylindrica* and/or *Sorghum nitidum* and/or *Mnesithea rottboellioides* closed grassland), notably that at the Ingham airport reserve. This is almost the entire extent of the 1% remaining of the regional ecosystem 7.3.32 currently on the cusp of extinction. Though invaded by numerous weed species, the dense sward of *Imperata cylindrica* has prevented weed dominance over a part of the area. Former burning regimes by indigenous locals probably kept these grasslands in a more diverse state, and possibly also prevented woody encroachment. Whilst adjacent deep-water wetlands have been recognised for their high conservation value (as illustrated by the recent development of the "Tyto wetlands" - a locally run conservation reserve), it is not clear whether the blady grass plain to the south is considered important locally. Clearly an increase in local awareness of the existence of this ecosystem is urgently required.

Other severely depleted ecosystems include several eucalypt open forest ecosystems that occurred on the better soils of the river levees and were cleared early for cultivation and for timber. Surprisingly now even very swampy tea-tree and paperbark ecosystems have been dramatically reduced in area – a testament to the effectiveness of planned and ongoing drainage programs, particularly in the Herbert and Tully floodplains.

Another vegetation community (*Eucalyptus tereticornis* open woodland to sparse woodland over a prominent secondary tree layer of *Melaleuca quinquenervia* and/or *M. viridiflora*.) has been depleted to near extinction. This community was formerly widespread across the Kennedy Valley (west of Cardwell) and the Murray River floodplain (south and south-west of Tully), and was probably highly suitable habitat for the now Endangered (Nature Conservation Act 1992) Mahogany Glider (*Petaurus gracilis*). This community contained mature, well spaced *Eucalyptus tereticornis* (suitable for roosting and gliding) and abundant *Melaleuca viridiflora* and *Melaleuca quinquenervia* both of which are food sources (Stephen Jackson NSW DPI pers. comm.). It is also highly probable that this community supported abundant *Myrmecodia beccarii* (listed as Vulnerable under the Nature Conservation Act 1992) since *Melaleuca viridiflora* is a favoured host. Although a few remnants of the vegetation community occur, their structure and composition has probably changed considerably due to logging and rainforest invasion. In addition a verification of the vegetation community type is necessary at the field level to be certain that they are indeed remnants of this community.

The rainforests, particularly those on basalts and on the river levees have been cleared extensively for their useful soils and timber. The former magnificence of these stands is evident on the historical aerial photographs where dense broad stands with diverse crown shapes and sizes clothed such rivers as the Herbert and Tully, and though often cleared before the photo record north of Tully, are clearly indicated on old land survey plans as covering entire valleys. Extremely sharp rainforest/open forest boundaries were the norm, suggesting the edges were kept stable by repetitive burning of the adjacent forests, the fires probably terminating abruptly upon reaching the wall of rainforest. Given the high species diversity typical of rainforest it is possible that plant species unknown to science have become extinct since clearing began in the Wet Tropics coastal lowlands.

It is very important to note that the small number of vegetation communities that are close to extinction once covered a large part of the Wet Tropics coastal lowlands. This means that we tend to underestimate the overall vegetation loss – especially given that a large number of the remaining types are not in the Endangered category under the Vegetation Management Act, 1999. It is easy for us to consider that these examples are "safe" when in fact they are really all that is left of our coastal lowlands, and yet with the exception of the mangrove ecosystems, they continue to be degraded and fragmented.

Generally when a vegetation community has been reduced to less than 10% of its pre-clearing extent, it is in a very fragmented and poor state, with depleted ecological functioning. For this reason any form of biodiversity assessment needs to take into account a variety of considerations, besides pre-clearing extent. The Environmental Protection Agency has developed the Biodiversity Assessment and Mapping Methodology (BAMM) (Environmental Protection Agency 2002) which ranks biodiversity significance of an area according to specified biodiversity values to account for ecological concepts such as rarity, diversity, fragmentation, habitat condition, resilience, threats, and ecosystem processes, and not just the status of the regional ecosystems. Through this methodology, "Biodiversity Planning Assessments" have been developed for 6 bioregions of Queensland, enabling land managers to access biological information and to understand the relative significance of any given area within the plan. This broad approach to assessment of the value of remnant vegetation is obviously preferable to using a single attribute such as the percent of pre-clearing remaining.

The introduction of Queensland State tree clearing laws (Vegetation Management Act 1999) followed by the cessation of broad-scale tree-clearing in December 2006, has substantially slowed the rate of clearing in most areas. However, the laws have been of only minimal advantage to the natural vegetation of the Wet Tropics lowlands, especially given that most areas suitable for agriculture on freehold land had already been cleared. The remaining areas that are now under the most threat of continued clearing and disturbance are in drier northern and western areas, and in the far south, particularly between Crystal Creek and Bluewater.

Exemptions under the Vegetation Management Act 1999 allow for legal clearing in areas, which have already been granted certain leases (eg. aquaculture), or for many areas occurring on urban or rural-residential zoning. They also allow for fence-line clearings and clearings for houses, infrastructure and dams. Forestry operations are currently also allowable on freehold land, being exempt from development approval for vegetation clearing providing the forest practice code is followed. The Vegetation Management Act 1999 provides no restrictions on grazing or deliberate alteration of the ground-stratum via mechanical means, fertilisation or sowing of pasture species. Changes to the zoning of land through the Integrated Planning Act (material change of use) can result in the clearing of remnant vegetation for uses such as urban expansion. Through this process, areas of less than two hectares are exempt from assessment under the Vegetation Management Act 1999. A new policy for the assessment of Material Change of Use applications came into force from December 2006 and it remains to be seen if this will provide any greater level of protection.

Other mechanisms for preventing degradation of Wet Tropics lowland vegetation outside of conservation reserves are becoming increasingly important. Voluntary conservation covenants (under amendments to the Land Act 1994) appear on the land title and bind successors in title. Some local governments are now using covenants to reward vegetation conservation through rate rebates. Nature Refuges (under the Nature Conservation Act 1992) enable landowners to obtain Environmental Protection Agency advice and assistance for management of native vegetation, and their management practices can also be made into binding land use agreements. The voluntary acquisition of land is another important mechanism, both by Federal and State governments, and by private conservation organisations. In some instances, conservation agreements and covenants can be placed on acquired land (to specify management practices and limit vegetation clearing), then the land resold. Tradeable rights and financial incentives (eg. rate rebates, water resources, vegetation clearing, carbon credits, and biodiversity offsets) are currently being investigated with the aim of placing a realistic economic value on environmental resources.

Conclusions

The documentation of pre-clearing vegetation in the Wet Tropics has been a revealing process. Clear, detailed photographs of lowland vegetation show numerous and extensive natural grasslands, broad bands of complex rainforest, and extensive forests and woodlands of *Melaleuca, Eucalyptus* and *Corymbia* species. These photos may have also recorded rapidly fading patterns of aboriginal landscape modification (including rainforest clearings and tracks). An array of additional air photos and land survey plans are yet to be examined, and could in future be used to refine the pre-clearing vegetation mapping. Other sources yet to be accessed include the full range of historical journal accounts, historical hand-held camera photos and indigenous knowledge. This paper and mapping coverage represents the beginning of a reconstruction of what the pre-clearing Wet Tropics vegetation was like. As a digital coverage it will be possible to improve the map as new information comes to light.

Comparison with current day mapping has shown that some of the mapped pre-clearing vegetation communities are extinct today, whilst several ecosystems have been reduced in area to less than 10% of their former extent. Prevention of further loss of significant ecosystems requires the application of various protective mechanisms, such as voluntary conservation covenants as well as the application of current vegetation management legislation.

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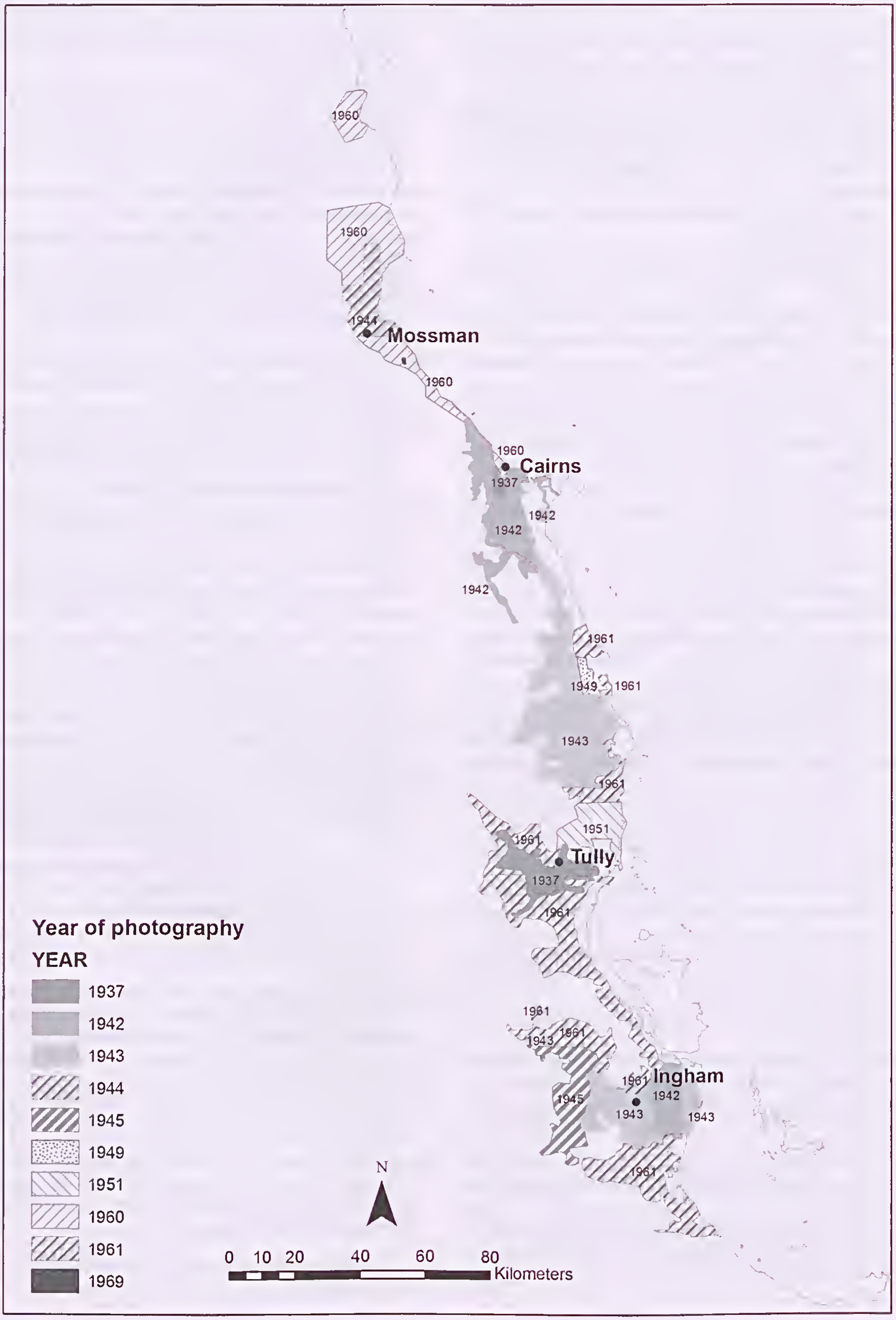
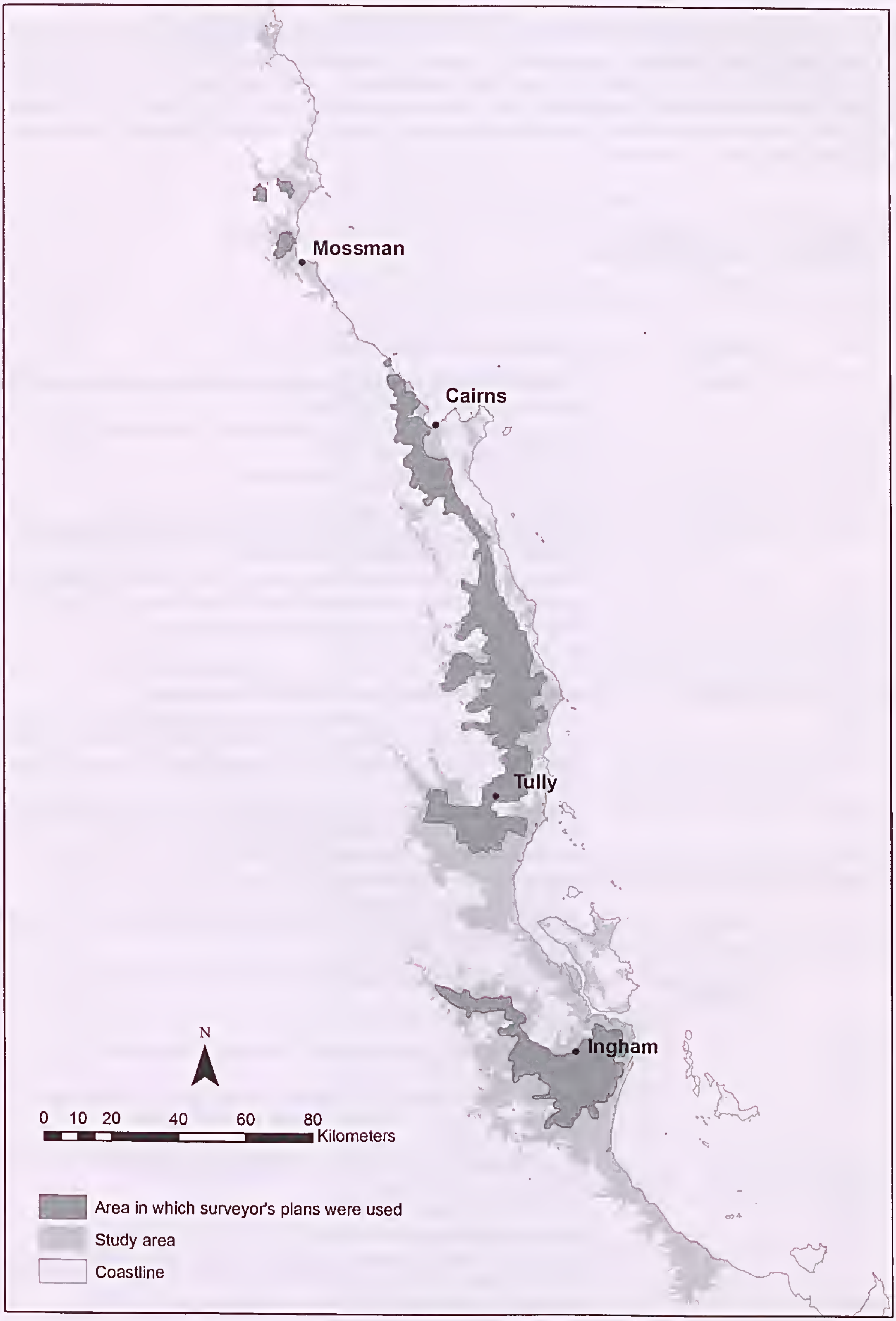
Appendix 1 Oldest aerial photographs utilised.



Appendix 2. Area for which historic surveyors plans were utilised.



Appendix 3. Regional ecosystems, vegetation communities and broad vegetation groups of the Wet Tropics Bioregion lowlands

Regional ecosystems and vegetation communities are as per Environmental Protection Agency (2005). Descriptions (in bold are summarised across vegetation communities to represent the regional ecosystem (RE) across its full range in the Wet Tropics bioregion (not just the lowlands). Vegetation communities (in regular text) that do not occur in the lowlands are not listed. The broad vegetation groups in this table were developed specifically for discussion in this manuscript and therefore differ to those in Environmental Protection Agency (2005). Where not indicated otherwise (eg estuarine, dune), broad vegetation groups occur on alluvium.

RE	Vegetation Community	Broad Vegetation Group (applied at RE level)	Description
7.1.1	7.1.1	**estuarine**	**Mangrove low closed forest to open shrubland.**
7.1.2		**estuarine**	***Sporobolus virginicus* grassland, samphire open forbland to sparse forbland, and bare saltpans, on plains adjacent to mangroves.**
	7.1.2a		Samphire flats with open forbland to sparse forbland of *Halosarcia* spp., and *Suaeda australis*. Includes bare saltpans.
	7.1.2b		*Sporobolus virginicus* (saltwater couch) grassland.
7.1.3		**estuarine**	***Schoenoplectus litoralis* and/or *Eleocharis dulcis* sparse sedgeland, or *Melaleuca quinquenervia* shrubland to open forest, in swamps which fluctuate periodically between freshwater and estaurine.**
	7.1.3a		*Schoenoplectus litoralis* (bulrush) and/or *Eleocharis dulcis* (bulkuru) sedgeland. May include scattered *Melaleuca quinquenervia* and/or mangrove species.
	7.1.3b		*Melaleuca quinquenervia* woodland, shrubland and open forest.
	7.1.3c		Water, in dune swamps.
7.1.4		**estuarine**	**Mangrove and vine forest communities of the brackish zone.**
	7.1.4a		Mesophyll vine forest/mangrove complex, of the brackish zone. Canopy species include *Heritiera littoralis, Bruguiera gymnorhiza, Sonneratia alba, Barringtonia racemosa, Archontophoenix alexandrae, Elaeocarpus grandis, Melicope elleryana, Acacia mangium* and *Syzygium tierneyanum.*
	7.1.4b		Simple mesophyll vine forest with canopy dominated by *Barringtonia racemosa* and/or *Hibiscus tiliaceus*. *Heritiera littoralis* is common on mangrove fringes.
	7.1.4c		Mangrove communities with *Livistona drudei* emergents.
	7.1.4d		Riverine communities dominated by *Nypa fruticans.*
7.1.5	7.1.5	**estuarine**	***Melaleuca viridiflora* or *Melaleuca* spp. ± *Acacia* spp. ± mangrove spp. open woodland, shrubland and open forest.**
7.2.1		**dune rainforests vinescrubs**	**Mesophyll vine forest on beach ridges and sand plains of beach origin.**
	7.2.1a		Complex mesophyll or mesophyll vine forest.
	7.2.1b		Mesophyll vine forest with *Intsia bijuga, Beilschmiedia obtusifolia*, and *Palaquium galactoxylon.*
	7.2.1c		Low to medium closed forest with *Calophyllum inophyllum, Terminalia arenicola, Dillenia alata, Myristica insipida, Pouteria obovoidea, Pongamia pinnata*, and *Hibiscus tiliaceus.*
	7.2.1d		Swampy mesophyll vine forest with *Archontophoenix alexandrae* (feather palm) in the sub-canopy.
	7.2.1e		Simple Notophyll vine forest with *Syzygium angophoroides.*
	7.2.1f		Simple notophyll vine forest with *Blepharocarya involucrigera, Acacia celsa, Flindersia bourjotiana, Syzygium angophoroides, Dillenia alata, Grevillea baileyana, Syzygium kuranda, Calophyllum sil, Backhousia hughesii, Acronychia acronychioides.*
	7.2.1g		Mesophyll vine forest with *Archontophoenix alexandrae* (feather palm).

	7.2.1h		Mesophyll vine forest with *Licuala ramsayi* (fan palm).
	7.2.1i		Mesophyll vine forest.
7.2.2		**dune rainforests vinescrubs**	**Notophyll to microphyll vine forest on beach ridges and sand plains of beach origin.**
	7.2.2a		Notophyll vine forests, often with *Acacia* emergents. Species commonly include *Cupaniopsis anacardioides, Diospyros geminata, Canarium australianum, Alphitonia excelsa, Acacia crassicarpa, Pleiogynium timarense, Chionanthus ramiflara, Mimusaps elengi, Polyalthia nitidissima, Pangamia pinnata, Geijera latifolia, Ficus opposita, Pouteria sericea, Terminalia muelleri, T. arenicola, Drypetes deplanchei*, and *Exocarpos latifolius.*
	7.2.2b		Closed shrubland and low closed forest with *Blepharocarya involucrigera, Randia sessilis, Choriceras tricarne, Endiandra glauca, Cyclophyllum multiflorum, Syzygium banksii, Polyscias australiana, Terminalia muellerii, Dillenia alata* and *Acacia polystachya.*
	7.2.2c		Simple notophyll vine forest dominated by *Blepharacarya involucrigera.* Sites subject to episodic disturbance or a seral stage of recovery from a single event or period of disturbance.
	7.2.2d		*Acacia mangium* closed forest, with *A. crassicarpa, Hibiscus tiliaceus, Cupaniapsis anacardioides, Pouteria obovata, Breynia stipata, Morinda citrifalia* and *Terminalia muelleri.*
	7.2.2e		Low notophyll vine thicket.
	7.2.2f		Microphyll vine thicket occurring in clumps/groves. Inter-grove areas are occupied by sparse grasses and herbs. Common tree species include *Mimusops elengi, Terminalia muelleri, Diospyros ferrea* var. *reticulata, Pouteria sericea, Ficus obliqua* var. *obliqua, Pleiogynium timorense, Canarium australianum, Exocarpas latifolius, Celtis paniculata, Maytenus fasciculiflara, Brucea javanica, Ximenia americana, Acacia oraria, Acacia leptocarpa* and *Persoonia falcata.*
	7.2.2g		Vine forest with *Hibiscus tiliaceus* and *Calophyllum australianum.*
	7.2.2h		Medium to tall semi-deciduous notophyll vine forest with species including *Melia azedarach, Pleiagynium timorense, Ganaphyllum falcatum, Paraserianthes taana, Ficus racemosa, Argyrodendron palyandrum*, and *Alstonia scholaris.*
7.2.3		**dune open forests**	***Carymbia tessellaris* and/or *Acacia crassicarpa* and/or *C. intermedia* and/or *C. clarksoniana* closed forest to woodland, of beach ridges, predominantly of Holocene age.**
	7.2.3a		*Carymbia tessellaris, C. clarksoniana* (and/or *C. intermedia*), *Melaleuca dealbata* ± *Lophostemon suaveolens*, open forest and woodland with *Acacia mangium, A. crassicarpa, Canarium australianum* and *Deplanchea tetraphylla.*
	7.2.3b		*Carymbia tessellaris* and *Corymbia clarksoniana* (or *C. intermedia*), woodland or open forest.
	7.2.3c		*Corymbia tessellaris* and *Corymbia clarksaniana* (or *C. intermedia*), woodland or open forest, with a very well developed vine forest understorey (due to infrequent burning).
	7.2.3d		*Carymbia intermedia* open forest.
	7.2.3e		*Carymbia intermedia* open forest, with a very well developed vine forest understorey (due to infrequent burning).
	7.2.3f		*Acacia crassicarpa* open to closed forest.
	7.2.3g		*Carymbia clarksoniana* woodland to open forest.
	7.2.3h		*Carymbia tessellaris, Acacia crassicarpa, Melaleuca leucadendra* and *M. viridiflara* woodland.
	7.2.3i		*Acacia crassicarpa* low closed forest (wind sheared).
	7.2.3j		*Carymbia clarksoniana, C. tessellaris* and *Acacia crassicarpa* woodland.
7.2.4		**dune open forests**	***Eucalyptus* spp. (often *E. pellita* or *Carymbia intermedia*) open forest and/or *Lophastemon suavealens* open forest on swampy sand plains of beach origin, and Pleistocene beach ridges.**
	7.2.4a		*Carymbia intermedia, Eucalyptus pellita, Lophostemon suavealens* and *Melaleuca dealbata* open forest to woodland.
	7.2.4b		*Eucalyptus tereticornis, Corymbia tessellaris, E. pellita, E. intermedia, Melaleuca dealbata, Lophostemon suaveolens, Acacia mangium* and *A. crassicarpa* woodland to open forest.

	7.2.4c		*Eucalyptus tereticornis, Corymbia tessellaris, E. pellita, E. intermedia, Melaleuca dealbata, Lophostemon suaveolens, Acacia mangium* and *A. crassicarpa*, woodland to open forest with a very well developed vine forest understorey.
	7.2.4d		*Eucalyptus pellita* and *Corymbia intermedia*, ± *C. tessellaris, E. tereticornis, Lophostemon suaveolens, Acacia celsa, A. cincinnata, A. mangium* and *A. flavescens* open forest.
	7.2.4e		*Eucalyptus pellita* and *Corymbia intermedia*, ± *C. tessellaris, E. tereticornis* and *Lophostemon suaveolens*, open forest to woodland with a very well developed vine forest understorey.
	7.2.4f		*Lophostemon suaveolens* ± *Corymbia tessellaris, Melaleuca* sp.aff. *viridiflora*, and *M. dealbata* woodland and open forest.
	7.2.4g		*Melaleuca dealbata* ± *M. leucadendra* open forest to woodland.
	7.2.4h		*Melaleuca dealbata, Lophostemon suaveolens, Corymbia tessellaris, Acacia mangium* and *Livistona drudei* open forest.
	7.2.4i		*Eucalyptus portuensis* open forest.
	7.2.4j		*Allocasuarina littoralis, Corymbia intermedia* and *Lophostemon suaveolens* open forest, woodland and shrubland.
	7.2.4k		*Acacia mangium* and *A. celsa* open to closed forest.
	7.2.4l		*Melaleuca leucadendra, M. viridiflora, M. dealbata, Acacia leptocarpa, A. crassicarpa, Excoecaria agallocha, Hibiscus tiliaceus* and *Thespesia populnea* woodland to low open forest.
	7.2.4m		*Acacia celsa* open to closed forest.
	7.2.4n		*Eucalyptus tereticornis* open forest and woodland.
7.2.5		**dune rainforests vinescrubs**	**Mesophyll/notophyll vine forest of *Syzgium forte* subsp. *forte* on beach ridges and sand plains of beach origin.**
	7.2.5a		Simple mesophyll to notophyll vine forest with *Syzygium forte* subsp. *forte, Buchanania arborescens, Pleiogynium timorense, Dillenia alata, Litsea fawcettiana*, and *Chionanthus ramiflora*.
	7.2.5b		*Acacia polystachya* dominant communities, mostly closed forest but includes some woodlands, with a lower layer of vine forest species.
7.2.6		**dune shrublands and heathlands**	**Mosaic of clumps of notophyll vine forest, sclerophyll spp. shrublands and open woodlands, and bare sand blows, on aeolian dunes.**
	7.2.6a		Open shrubland to low open forest.
	7.2.6b		Evergreen notophyll vine thicket with *Acacia crassicarpa, Elaeodendron melanocarpum, Aglaia elaeagnoidea* and *Drypetes deplanchei*.
	7.2.6c		Complex of open to closed shrublands, grasslands and low to medium woodlands and forests. Includes pure stands of *Casuarina equisetifolia*, and open to closed woodlands dominated by *Acacia crassicarpa, Syzygium forte* subsp. *forte*, and *Calophyllum inophyllum* and *Pandanus* sp.
7.2.7		**dune casuarina**	***Casuarina equisetifolia* ± *Corymbia tessellaris* open forest ± groved vine forest shrublands of the beach strand and foredune.**
	7.2.7a		Complex of open to closed shrublands, grasslands and low to medium woodlands and forests. Includes pure stands of *Casuarina equisetifolia*, and open to closed woodlands dominated by *Acacia crassicarpa, Syzygium forte* subsp. *forte, Calophyllum inophyllum* and *Pandanus* sp.
	7.2.7b		Groved shrubland with *Corymbia tessellaris, Casuarina equisetifolia* and vine forest species including *Canarium australianum, Terminalia arenicola, Pouteria sericea*.
	7.2.7c		Areas of open sand.
7.2.8	7.2.8	**dune paperbark forests**	***Melaleuca leucadendra* open forest to woodland.**
7.2.9		**dune paperbark forests**	***Melaleuca quinquenervia* shrubland to closed forest, or *Lepironia articulata* open to closed sedgeland on dune swales and swampy sand plains of beach origin.**
	7.2.9a		*Melaleuca quinquenervia* open forest to woodland and shrubland.
	7.2.9b		Mixed sedgeland-shrubland complex with *Melaleuca quinquenervia*.
	7.2.9c		*Lepironia articulata* sedgeland.
	7.2.9d		*Melaleuca quinquenervia* and *Acacia crassicarpa* open forest and woodland.

7.2.10		**dune shrublands and heathlands**	**Shrubland, sedgeland and heath complex with *Thryptomene oligandra* and/or *Asteromyrtus* spp., ± *Melaleuca quinquenervia* on sand plains of beach origin.**
	7.2.10a		*Thryptomene oligandra* low open forest, closed shrubland and heath complex.
	7.2.10b		*Asteromyrtus lysicephala, Asteromyrtus angustifolia, Thryptomene oligandra, Acacia crassicarpa, Jacksonia thesioides, Leucopogon yorkensis, Hibbertia banksii, Canthium coprosmoides* and *Aidia racemosa* open to closed scrub and heath.
	7.2.10c		Low open forest, shrubland and sedgeland complex with *Melaleuca quinquenervia, Asteromyrtus lysicephala, Deplanchea tetraphylla, Dillenia alata, Gahnia sieberiana, Pandanus sp., Lepironia articulata, Nepenthes mirabilis, Blechnum indicum* and *Myrmecodia beccarii.*
	7.2.10d		*Allocasuarina littoralis* woodland and open forest.
	7.2.10e		*Acacia flavescens, Allocasuarina littoralis* and *Allocasuarina torulosa* low shrubby open forest to woodland.
7.2.11		**dune paperbark forests**	***Melaleuca viridiflora* ± *Lophostemon suaveolens* ± emergent *Eucalyptus* spp. woodland to open forest, or *Melaleuca* sp. aff. *viridiflora* open forest to woodland, on swampy sand plains of beach origin.**
	7.2.11a		*Melaleuca viridiflora* woodland to open forest.
	7.2.11b		*Melaleuca viridiflora*, and *Lophostemon suaveolens* woodland.
	7.2.11c		*Melaleuca viridiflora, Lophostemon suaveolens* and *Allocasuarina littoralis* open shrubland.
	7.2.11d		Complex of *Melaleuca quinquenervia* shrublands and open forests, and *Melaleuca viridiflora, Lophostemon suaveolens* and *Allocasuarina littoralis* low woodland and open forest.
	7.2.11e		*Melaleuca* sp. aff. *viridiflora* open forest and woodland.
	7.2.11f		*Melaleuca quinquenervia* and *Melaleuca viridiflora* open grassy woodland.
	7.2.11g		*Corymbia clarksoniana, Eucalyptus platyphylla, Lophostemon suaveolens, E. drepanophylla* and *Melaleuca viridiflora* open woodland.
	7.2.11h		Grassland, probably dominated by *Imperata cylindrica* (all extinct).
7.3.1		**grassland and sedgeland**	***Hemarthria uncinata* and/or *Ischaemum australe* and/or *Cynodon dactylon* grassland, and/or ephemeral sedgelands, on seasonally inundated alluvial plains.**
	7.3.1a		*Hemarthria uncinata* and/or *Ischaemum australe* subsp. *arundinaceum* closed grassland.
	7.3.1b		*Cynodon dactylon* grassland.
	7.3.1c		Ephemeral freshwater swamp dominated by sedges.
7.3.3		**palm swamps**	**Mesophyll vine forest with *Archontophoenix alexandrae* on poorly drained alluvial plains.**
	7.3.3a		Mesophyll vine forest with *Archontophoenix alexandrae* (feather palm).
	7.3.3c		Mesophyll vine forest with dominant *Syzygium tierneyanum* and/or *Barringtonia racemosa* and sub-canopy dominated by *Archontophoenix alexandrae* (feather palm).
7.3.4	7.3.4	**palm swamps**	**Mesophyll vine forest with *Licuala ramsayi* (fan palm).**
7.3.5		**paperbark forests**	***Melaleuca quinquenervia* and/or *Melaleuca cajuputi* closed forest to shrubland on poorly drained alluvial plains.**
	7.3.5a		*Melaleuca quinquenervia* open forest, woodland and shrubland.
	7.3.5b		Mixed shrubland-sedgeland complex with *Melaleuca quinquenervia*.
	7.3.5c		*Melaleuca cajuputi* open forest to woodland.
	7.3.5d		*Melaleuca quinquenervia* and *M. viridiflora* open grassy woodland with a dense grassy ground layer, usually dominated by *Ischaemum australe* and *Isachne globosa*.
	7.3.5e		*Melaleuca quinquenervia* and *Lophostemon suaveolens* open shrubland with a ground layer of by *Ischaemum australe* var. *arundinaceum*.
7.3.6		**paperbark forests**	***Melaleuca dealbata* ± *Melaleuca leucadendra* open forest on poorly drained alluvial plains.**
	7.3.6a		*Melaleuca dealbata* ± *M. leucadendra* open forest to woodland. Includes two areas on the northeastern edge of Wharps Holding that are young dense recruiting stands of *Melaleuca dealbata* which have taken over naturally open areas. The reason for this recruitment is unclear.

	7.3.6b		*Melaleuca dealbata* open forest.
7.3.7		**open forests**	***Eucalyptus pellita* and *Corymbia intermedia* open forest to woodland (or vine forest with emergent *E. pellita* and *C. intermedia*), on poorly drained alluvial plains.**
	7.3.7a		*Eucalyptus pellita* and *Corymbia intermedia* open forest and woodland.
	7.3.7b		*Eucalyptus pellita* and *Corymbia intermedia* open forest and woodland, with a very well developed vine forest understorey.
	7.3.7c		*Corymbia intermedia, Eucalyptus pellita, Lophostemon suaveolens* and *Melaleuca dealbata* open forest and woodland.
7.3.8		**teatree**	***Melaleuca viridiflora* ± *Eucalyptus* spp. ± *Lophostemon suaveolens* open forest to open woodland on alluvial plains.**
	7.3.8a		*Melaleuca viridiflora* open forest to open woodland. Includes areas of natural invasion onto former grasslands.
	7.3.8b		*Melaleuca viridiflora* open forest to open woodland with eucalypt emergents (or sparse eucalypt overstorey) of species such as *Corymbia clarksoniana, Eucalyptus platyphylla, Lophostemon suaveolens* and *E. drepanophylla*.
	7.3.8c		*Melaleuca viridiflora*, and *Lophostemon suaveolens* open forest to woodland.
	7.3.8d		*Melaleuca viridiflora, Lophostemon suaveolens* and *Allocasuarina littoralis* open shrubland.
7.3.9		**open forests**	***Corymbia tessellaris, Acacia* spp., *Melaleuca* spp., open forest on poorly drained alluvial plains.**
	7.3.9a		*Melaleuca dealbata, Lophostemon suaveolens, Corymbia tessellaris, Acacia mangium* ± *Livistona drudei* open forest.
	7.3.9b		*Corymbia tessellaris, Acacia crassicarpa, Melaleuca leucadendra, M. viridiflora* woodland to open forest.
7.3.10		**rainforest**	**Simple to complex mesophyll to notophyll vine forest on moderate to poorly drained alluvial plains of moderate fertility.**
	7.3.10a		Mesophyll vine forest.
	7.3.10c		Mesophyll vine forest with scattered *Archontophoenix alexandrae* (feather palm) in the sub-canopy.
	7.3.10d		Open areas in vine forests dominated by sprawling vines, with emergent vine-draped trees or clumps of trees. Vines commonly include *Merremia peltata*.
	7.3.10e		Simple notophyll vine forest with *Blepharocarya involucrigera, Acacia celsa, Flindersia bourjotiana, Syzygium angophoroides, Dillenia alata, Grevillea baileyana, Syzygium kuranda, Calophyllum sil, Backhousia hughesii* and *Acronychia acronychioides*.
	7.3.10f		Simple Notophyll vine forest with *Syzygium angophoroides*.
	7.3.10g		Simple notophyll vine forest dominated by *Blepharocarya involucrigera*.
7.3.12		**open forests**	**Mixed eucalypt open forest to woodland, dominated by *Eucalyptus tereticornis* and *Corymbia tessellaris* ± *Melaleuca dealbata*, (or vine forest with these species as emergents), on alluvial plains of lowlands.**
	7.3.12a		*Eucalyptus tereticornis, Corymbia tessellaris, E. pellita, C. intermedia, Melaleuca dealbata* and *Lophostemon suaveolens* woodland to open forest, often with a secondary tree layer of *Acacia mangium* and *A. crassicarpa*.
	7.3.12b		*Eucalyptus tereticornis, Corymbia tessellaris, E. pellita, C. intermedia, Melaleuca dealbata* and *Lophostemon suaveolens* woodland to open forest, often with a secondary tree layer of *Acacia mangium* and *A. crassicarpa*, and with a very well developed vine forest understorey.
	7.3.12c		*Eucalyptus tereticornis* open woodland to sparse woodland over a prominent secondary tree layer of *Melaleuca quinquenervia* and/or *M. viridiflora*.
7.3.13	7.3.13	**woodland**	***Corymbia nesophila* open forest to woodland.**
7.3.16		**woodland**	***Eucalyptus platyphylla* woodland to open forest on alluvial plains.**
	7.3.16a		*Eucalyptus platyphylla, Corymbia clarksoniana, Lophostemon suaveolens* woodland, or *E. platyphylla, Lophostemon suaveolens, C. tessellaris* open forest.
	7.3.16b	woodland	*Eucalyptus platyphylla, Lophostemon suaveolens, Corymbia clarksoniana, C. tessellaris* open forest with a prominent shrub layer of *Acacia* spp., *Planchonia careya*, ± vine forest elements.
	7.3.16c		*Eucalyptus platyphylla* grassy woodland to open woodland.

7.3.17	7.3.17	**rainforest**	**Complex mesophyll vine forest.**
7.3.19		**open forests**	***Corymbia intermedia* or *C. tessellaris* ± *Eucalyptus tereticornis* open forest (or vine forest with these species as emergents), on well drained alluvium.**
	7.3.19a		*Corymbia intermedia, Eucalyptus tereticornis, E. drepanophylla, Allocasuarina torulosa, Allocasuarina littoralis, Lophostemon suaveolens*, woodland with *Acacia cincinnata, A. flavescens, Banksia aquilonia* and *Xanthorrhoea johnsonii.*
	7.3.19b		*Corymbia tessellaris* and *C. intermedia* woodland and open forest.
	7.3.19c		*Corymbia tessellaris* and *C. intermedia* woodland and open forest with a very well developed vine forest understorey.
	7.3.19d		*Corymbia intermedia* open forest.
	7.3.19e		*Corymbia intermedia* open forest with a very well developed vine forest understorey.
	7.3.19h		*Corymbia tessellaris* ± *Eucalyptus tereticornis, C. intermedia, E. drepanophylla, E. platyphylla* and *Lophostemon suaveolens* layered grassy woodland with *Acacia celsa* and *Cycas media.*
	7.3.19j		*Themeda triandra* and *Imperata cylindrica* grassland.
7.3.20		**open forests**	***Corymbia intermedia* and *Syncarpia glomulifera*, or *C. intermedia* and *Eucalyptus pellita*, or *Syncarpia glomulifera* and *Allocasuarina* spp., or *E. cloeziana*, or *C. torelliana* open forests (or vine forests with these species as emergents), on alluvial fans at the bases of ranges.**
	7.3.20a		*Eucalyptus pellita, Corymbia intermedia, C. tessellaris*, open forest often with *Acacia celsa, A. cincinnata, A. mangium* and *A. flavescens.* Includes small areas dominated by *A. crassicarpa.*
	7.3.20b		*Eucalyptus pellita, Corymbia intermedia, C. tessellaris*, open forest often with *Acacia celsa, A. cincinnata, A. mangium* and *A. flavescens*, with a very well developed vine forest understorey.
	7.3.20c		*Syncarpia glomulifera, Corymbia intermedia, Eucalyptus pellita, E. tereticornis*, open forest often with *Acacia celsa* and *A. mangium.*
	7.3.20d		*Corymbia intermedia, Syncarpia glomulifera, Lophostemon confertus* open forest with *Allocasuarina torulosa* and *Banksia aquilonia.*
	7.3.20e		*Corymbia intermedia, Eucalyptus pellita, E. tereticornis, C. tessellaris, C. torelliana*, open forest, often with *Acacia celsa, A. mangium, Lophostemon suaveolens*, and *Syncarpia glomulifera.*
	7.3.20f		*Corymbia intermedia, Eucalyptus pellita, E. tereticornis, C. tessellaris, C. torelliana*, open forest with a very well developed vine forest understorey, and often with *Acacia celsa, A. mangium, Lophostemon suaveolens*, and *Syncarpia glomulifera.*
	7.3.20g		Simple notophyll vine forest with *Corymbia torelliana, Eucalyptus tereticornis, C. intermedia, E. pellita, Acacia celsa, A. cincinnata* and *A. polystachya* emergents and co-dominants.
	7.3.20h		*Acacia mangium* and *Lophostemon suaveolens* open forest with scattered emergent sclerophyll species including *Eucalyptus pellita, Corymbia tessellaris* and *C. intermedia.*
	7.3.20i		*Syncarpia glomulifera, Allocasuarina torulosa* and/or *A. littoralis* open forest and woodland.
	7.3.20j		*Syncarpia glomulifera, Allocasuarina torulosa* and/or *A. littoralis* open forest and woodland with a very well developed vine forest understorey.
	7.3.20k		*Eucalyptus cloeziana* open forest.
	7.3.20l		*Syncarpia glomulifera, Corymbia intermedia, Allocasuarina littoralis* woodland, low woodland and open forest with *Banksia aquilonia, Acacia flavescens* and *Xanthorrhoea johnsonii.*
	7.3.20m		*Acacia flavescens, Allocasuarina littoralis* and *A. torulosa* low shrubby open forest to woodland.
7.3.21		**open forests**	***Eucalyptus portuensis* ± *Corymbia intermedia* open forest to woodland on alluvium.**
	7.3.21a		*Eucalyptus portuensis, Corymbia intermedia, E. drepanophylla, E. platyphylla, E. tereticornis, C. tessellaris, Lophostemon suaveolens, Syncarpia glomulifera* open forest to woodland. May include small areas of *Acacia leptostachya* dominated communities.
	7.3.21b		*Eucalyptus portuensis, E. drepanophylla, Corymbia intermedia, Lophostemon suaveolens* low to medium woodland with *Melaleuca viridiflora, Acacia flavescens* and *Allocasuarina littoralis.*

	7.3.21c		*Corymbia intermedia, Eucalyptus portuensis, E. drepanophylla, E. platyphylla, C. tessellaris, E. tereticornis, Syncarpia glomulifera, Lophostemon suaveolens, L. confertus* woodland to low woodland with *Xanthorrhoea johnsonii* and *Cycas media.*
7.3.23		rainforest	**Simple to complex semi-deciduous notophyll to mesophyll vine forest on lowland alluvium.**
	7.3.23a		Simple-complex semi-deciduous notophyll to mesophyll vine forest.
	7.3.23b		Semi-deciduous vine forest with *Nauclea orientalis, Cryptocarya hypospodia* and *Castanospermum australe.*
7.3.25		paperbark forests	***Melaleuca leucadendra* ± vine forest species, open to closed forest, on alluvium fringing streams.**
	7.3.25a		*Melaleuca leucadendra* open forest and woodland.
	7.3.25b		*Melaleuca leucadendra* and *Eucalyptus tereticornis*, layered open forest, and closed forest with a vine forest understorey.
	7.3.25c		Closed forest of *Tristaniopsis exiliflora* and *Xanthostemon chrysanthus.*
7.3.26		casuarina	***Casuarina cunninghamiana* woodland to open forest on alluvium fringing streams.**
	7.3.26a		*Casuarina cunninghamiana, Eucalyptus tereticornis, Lophostemon suaveolens, Melaleuca leucadendra, M. fluviatilis, Buckinghamia celsissima, Mallotus philippensis* woodland and forest with an understorey of *Callistemon viminalis* and *Bursaria tenuifolia.*
	7.3.26b		*Casuarina cunninghamiana* woodland and forest.
7.3.28		stream beds	**Rivers and streams including riparian herbfield and shrubland on river and stream bed alluvium, and rock within stream beds.**
	7.3.28a		Water from natural non-tidal rivers.
	7.3.28b		Bare sand or silt, herblands, grasslands, shrublands and woodlands (exotic species, particularly of grasses and herbs may dominate).
	7.3.28c		*Callistemon viminalis* shrubland.
	7.3.28d		Unvegetated rock.
7.3.29		grassland and sedgeland	**Sedgelands and grasslands of permanently and semi-permanently inundated swamps, including areas of open water.**
	7.3.29a		Complex of sedgelands, grasslands, fernlands and forblands. Prominent species include *Cyperus lucidus, Actinoscirpus grossus, Lepironia articulata, Scleria poiformis, Gahnia sieberiana, Panicum paludosum, Isachne globosa, Blechnum indicum* and *Persicaria* sp.
	7.3.29b		Open water.
7.3.30	7.3.30	fernland	**Complex of fernlands and sedgelands with emergent rainforest pioneering spp.**
7.3.31	7.3.31	grassland and sedgeland	***Lepironia articulata* sedgeland to open sedgeland.**
7.3.32		grassland and sedgeland	***Imperata cylindrica* and/or *Sorghum nitidum* and/or *Mnesithea rottboellioides* and/or *Themeda triandra* closed tussock grassland on alluvial plains.**
	7.3.32a		*Imperata cylindrica* and/or *Sorghum nitidum* and/or *Mnesithea rottboellioides* closed grassland.
	7.3.32b		Grassland dominated by *Themeda triandra.*
7.3.34	7.3.34	paperbark forests	***Melaleuca* sp. aff. *viridiflora* (undescribed taxon) open to closed forest.**
7.3.35		acacia	***Acacia mangium* and/or *A. celsa* and/or *A. polystachya* closed forest on alluvial plains.**
	7.3.35a		*Acacia mangium* and *A. celsa* open to closed forest.
	7.3.35b		*Acacia celsa* open to closed forest.
	7.3.35c		*Acacia polystachya* closed forest, or *A. polystachya* woodland with a secondary layer of vine forest species.
7.3.36		rainforest	**Complex mesophyll vine forest of high rainfall, cloudy uplands on alluvium.**
	7.3.36b		Simple notophyll vine forest.
7.3.38	7.3.38	rainforest	**Complex notophyll vine forest with emergent *Agathis robusta.***
7.3.40	7.3.40	open forests	***Eucalyptus tereticornis* open forest.**

7.3.43		open forests	***Eucalyptus tereticornis* open forest to woodland, on uplands on well drained alluvium.**
	7.3.43a		*Eucalyptus tereticornis* open forest, tall open forest and woodland including communities ranging from those dominated by *E. tereticornis* to mixtures of that species with *Corymbia intermedia, E. drepanophylla, Lophostemon suaveolens* and *Allocasuarina torulosa.*
7.3.44	7.3.44	open forests	***Eucalyptus leptophleba* ± *Corymbia clarksoniana* open forest to woodland.**
7.3.45		open forests	***Corymbia clarksoniana* ± *C. tessellaris* ± *Eucalyptus drepanophylla* open forest to open woodland on alluvial plains.**
	7.3.45a		*Eucalyptus drepanophylla, Corymbia clarksoniana,* ± *E. platyphylla,* ± *C. tessellaris,* ± *C. dallachiana* woodland to open forest.
	7.3.45b		*Corymbia clarksoniana* woodland to open forest. May include small areas of *Acacia leptostachya* shrubland.
	7.3.45c		*Corymbia clarksoniana* and *C. tessellaris* ± *E. tereticornis* ± *E. platyphylla* ± *Lophostemon suaveolens* ± *Melaleuca dealbata* ± *C. dallachiana* woodland.
	7.3.45d		*Corymbia tessellaris, C. intermedia, C. clarksoniana* grassy woodland, open woodland and sparse woodland occurring only on the Palm Islands.
	7.3.45e		Woodland with *Corymbia clarksoniana* in the Cowie Point and Duncans Flat area.
	7.3.45f		*Corymbia clarksoniana* dense open forest, with *Melaleuca dealbata, Eucalyptus platyphylla, C. tessellaris, Lophostemon suaveolens*, and occasionally *E. pellita.* Dense secondary tree layer of *Alphitonia excelsa, Acacia oraria, A. mangium, A. crassicarpa, A. flavescens, Pandanus* sp., and *Planchonia careya.* (This is an extinct vegetation community).
7.3.46	7.3.46	open forests	***Lophostemon suaveolens* open forest to woodland.**
7.3.47	7.3.47	open forests	***Allocasuarina littoralis, Corymbia intermedia* and *Lophostemon suaveolens* open forest.**
7.3.49		rainforest	**Notophyll vine forest on rubble terraces of streams.**
	7.3.49a		*Tristaniopsis exiliflora* and *Xanthostemon chrysanthus* medium to tall layered open forest, and medium closed forest. Common associated species include *Grevillea baileyana, G. hilliana*, and *Blepharocarya involucrigera.*
	7.3.49c		Mixed open forest, low open forest, low closed forest, vine woodland, and open scrub with *Lophostemon suaveolens, Chionanthus ramiflora, Acacia flavescens*, and in areas of open scrub *Pittosporum spinescens* and *Wikstroemia indica.*
7.3.50		paperbark forests	***Melaleuca fluviatilis* ± vine forest species, open to closed forest, on alluvium fringing streams.**
	7.3.50a		*Melaleuca fluviatilis* open forest and woodland, often with *Casuarina cunninghamiana, Eucalyptus tereticornis, Lophostemon suaveolens, Corymbia intermedia* and *Nauclea orientalis.*
	7.3.50b		Low notophyll vine thicket with emergent *Melaleuca fluviatilis.*
7.8.1		rainforest	**Complex mesophyll vine forest on well drained basalt lowlands and foothills.**
	7.8.1a		Complex mesophyll vine forest.
	7.8.1b		Complex mesophyll vine forest on lateritic soils.
7.8.2		rainforest	**Complex notophyll to mesophyll vine forest of high rainfall, cloudy uplands on basalt.**
	7.8.2a		Complex mesophyll vine forest.
7.8.7		open forests	***Eucalyptus tereticornis* open forest, and associated grasslands, predominantly on basalt uplands.**
	7.8.7a		*Eucalyptus tereticornis* open forest, tall open forest and woodland. May also include *Corymbia intermedia, E. drepanophylla, Lophostemon suaveolens* and *Allocasuarina torulosa.*
	7.8.7b		Grassland dominated by *Themeda triandra.*
	7.8.7c		Grassland of unknown composition, possibly *Imperata cylindrica.*
7.8.11		rainforest	**Closed vineland of wind disturbed vine forest on basalt.**
	7.8.11a		Open areas in vine forests with sprawling vines and emergent vine-draped trees or clumps of trees. *Merremia peltata* is often present.

	7.8.11b		Complex mesophyll on very wet and wet lowlands, suffering from extreme wind damage where at least half the canopy has been destroyed.
7.8.12	7.8.12	**rainforest**	**Complex notophyll vine forest dominated by *Backhousia bancroftii*.**
7.8.14	7.8.14	**rainforest**	**Complex notophyll vine forest with emergent *Agathis robusta*.**
7.8.18		**open forests**	***Corymbia intermedia* and/or *Lophostemon suaveolens* ± *Allocasuarina torulosa* open forest to woodland on basalt.**
	7.8.18a		*Corymbia intermedia, Eucalyptus tereticornis, E. granitica* open forest to woodland with *Allocasuarina torulosa, A. littoralis, Lophostemon suaveolens, Acacia cincinnata, A. flavescens, Banksia aquilonia* and *Xanthorrhoea johnsonii.*
	7.8.18b		Corymbia intermedia open forest, with a very well developed vine forest understorey.
7.8.19	7.8.19	**open forests**	***Corymbia clarksoniana* open forest to woodland.**
7.11.1		**rainforest on hills**	**Simple to complex mesophyll to notophyll vine forest on moderately to poorly drained metamorphics (excluding amphibolites) of moderate fertility of the moist and wet lowlands, foothills and uplands.**
	7.11.1a		Mesophyll vine forest.
	7.11.1g		Mesophyll vine forest with scattered *Archontophoenix alexandrae* (feather palm) in the sub-canopy.
7.11.5		**open forests on hills**	***Eucalyptus pellita* ± *Corymbia intermedia* open forest (or vine forest with *E. pellita* and *C. intermedia* emergents), on metamorphics.**
	7.11.5a		*Eucalyptus pellita, Corymbia intermedia, C. tessellaris* open forest with *Acacia celsa, A. cincinnata, A. mangium* and *A. flavescens.*
	7.11.5b		*Eucalyptus pellita, Corymbia intermedia, C. tessellaris* open forest with *Acacia celsa, A. cincinnata, A. mangium* and *A. flavescens* and with a very well developed vine forest understorey.
	7.11.5c		*Corymbia intermedia, Eucalyptus pellita, E. tereticornis, C. tessellaris, C. torelliana*, open forest to woodland with *Acacia celsa, A. mangium, Lophostemon suaveolens* and *Syncarpia glomulifera.*
	7.11.5d		*Corymbia intermedia, Eucalyptus pellita, E. tereticornis, C. tessellaris, C. torelliana*, open forest to woodland with *Acacia celsa, A. mangium, Lophostemon suaveolens* and *Syncarpia glomulifera*, and with a very well developed vine forest understorey.
	7.11.5e		*Eucalyptus pellita* and *Corymbia intermedia* open forest and woodland.
7.11.7		**rainforest on hills**	**Complex notophyll vine forest with *Agathis robusta* emergents, on metamorphics of moist foothills and uplands.**
	7.11.7a		Complex notophyll vine forests (with emergent *Agathis robusta*).
7.11.8		**acacia on hills**	***Acacia polystachya* woodland to closed forest, or *Acacia mangium* and *Acacia celsa* open to closed forest, on metamorphics.**
	7.11.8b		*Acacia mangium* and *A. celsa* open to closed forest.
7.11.16		**open forests on hills**	***Eucalyptus portuensis* and *Corymbia intermedia* open forest to woodland, on wet and moist metamorphics of foothills and uplands.**
	7.11.16a		*Eucalyptus portuensis, Corymbia intermedia, E. drepanophylla, E. platyphylla, E. tereticornis, C. tessellaris, Lophostemon suaveolens, Syncarpia glomulifera* open forest to woodland.
7.11.18		**open forests on hills**	***Corymbia intermedia* and/or *C. tessellaris* ± *Eucalyptus tereticornis* medium to tall open forest to woodland (or vine forest with these species as emergents), on coastal metamorphic headlands and near-coastal foothills.**
	7.11.18a		*Corymbia intermedia* open forest to tall open forest.
	7.11.18b		*Corymbia intermedia* open forest to tall open forest with a very well developed vine forest understorey.
	7.11.18d		*Corymbia intermedia* open forest to tall open forest with a very well developed vine forest understorey.
	7.11.18e		*Corymbia tessellaris* and *C. intermedia* woodland to tall woodland and open forest.
	7.11.18g		*Eucalyptus tereticornis, Corymbia tessellaris, C. intermedia, E. drepanophylla, E. platyphylla, Lophostemon suaveolens* woodland and low layered grassy woodland with *Acacia aulacocarpa* and *Cycas media.*
	7.11.18h		*Eucalyptus tereticornis, Corymbia tessellaris, E. pellita, E. intermedia, Melaleuca dealbata, Lophostemon suaveolens* woodland, low woodland and open forest with *Acacia mangium* and *A. crassicarpa.*
7.11.19		**open forests on hills**	***Corymbia intermedia* and/or *Lophostemon suaveolens* open forest to woodland of uplands, on metamorphics.**

	7.11.19a		*Corymbia intermedia, Eucalyptus tereticornis, Allocasuarina torulosa, A. littoralis* and *Lophostemon suaveolens* open forest, low open forest and woodland with *Acacia cincinnata, A. flavescens, Banksia aquilonia* and *Xanthorrhoea johnsonii.*
	7.11.19c		*Lophostemon suaveolens* woodland and open forest.
7.11.25		**rainforest on hills**	**Simple-complex mesophyll to notophyll vine forest on amphibolites of the very wet lowlands and foothills.**
	7.11.25a		Mesophyll to notophyll vine forest.
7.11.26		**shrubland on hills**	**Rock pavements with *Allocasuarina littoralis* and *Syncarpia glomulifera* open to closed shrublands or *Bombax ceiba* and *Cochlospermum gillivraei* open woodland, or *Acacia* spp. shrubland, on metamorphics.**
	7.11.26a		*Acacia flavescens, Allocasuarina littoralis* and *Allocasuarina torulosa* low shrubby open forest to woodland.
	7.11.26f		Bare rock.
7.11.34		**shrubland on hills**	**Complex of shrublands, low heathy or shrubby woodlands and low forests, with *Corymbia tessellaris* and *C. intermedia* or *Melaleuca viridiflora, Allocasuarina* spp. and *Acacia* spp. on metamorphic coastal headlands and islands.**
	7.11.34a		Woodland, low woodland, low forest and shrubland with *Corymbia tessellaris, C. intermedia, Lophostemon suaveolens, Eucalyptus platyphylla, Melaleuca viridiflora, Acacia crassicarpa, A. flavescens, A. celsa, A. polystachya, Dillenia alata, Randia sessilis,* and *Canthium coprosmoides.*
	7.11.34c		Heath shrubland and grassland complex of coastal headlands with *Melaleuca viridiflora, Allocasuarina littoralis, Casuarina equisetifolia, Lophostemon suaveolens, Acacia holosericea, A. polystachya, Lophostemon grandiflorus, A. calyculata, Thryptomene oligandra, Pittosporum ferrugineum, Xanthorrhoea johnsonii* and *Alyxia spicata.*
	7.11.34d		Bare rock on coastal headlands.
7.11.39		**grassland and sedgeland on hills**	***Themeda triandra*, or *Imperata cylindrica, Sorghum nitidum* and *Mnesithea rottboellioides* closed tussock grassland, on metamorphic headlands and near-coastal hills.**
	7.11.39c		*Imperata cylindrica, Sorghum nitidum* and *Mnesithea rottboellioides* grassland.
7.11.43	7.11.43	**open forests on hills**	***Corymbia clarksoniana* ± *C. tessellaris* open forest to woodland.**
7.11.44	7.11.44	**open forests on hills**	***Eucalyptus tereticornis* open forest to woodland.**
7.11.47	7.11.47	**woodland on hills**	***Corymbia nesophila* open forest.**
7.11.49	7.11.49	**open forests on hills**	***Eucalyptus leptophleba, Corymbia clarksoniana* and *E. platyphylla* open forest to woodland.**
7.11.50		**woodland on hills**	***Eucalyptus platyphylla* ± *E. drepanophylla* ± *Corymbia* spp. open woodland to open forest on metamorphics.**
	7.11.50a		*Eucalyptus platyphylla, E. drepanophylla, Corymbia intermedia, Lophostemon suaveolens* open woodland to open forest.
7.11.51		**open forests on hills**	***Corymbia clarksoniana* and/or *Eucalyptus drepanophylla* open forest to woodland on metamorphics.**
	7.11.51a		*Corymbia clarksoniana, Eucalyptus tereticornis, E. drepanophylla* woodland, low woodland to open forest with *Allocasuarina torulosa, Allocasuarina littoralis, Lophostemon suaveolens, Acacia cincinnata, A. flavescens, Banksia aquilonia* and *Xanthorrhoea johnsonii.*
7.12.1		**rainforest on hills**	**Simple to complex mesophyll to notophyll vine forest on moderately to poorly drained granites and rhyolites of moderate fertility of the moist and wet lowlands, foothills and uplands.**
	7.12.1a		Mesophyll to notophyll vine forest.
7.12.2		**rainforest on hills**	**Notophyll or mesophyll vine forest with *Archontophoenix alexandrae* or *Licuala ramsayi*, on granites and rhyolites.**
	7.12.2c		Notophyll to mesophyll vine forest with *Archontophoenix alexandrae.*
7.12.4	7.12.4	**open forests on hills**	***Syncarpia glomulifera* ± *Eucalyptus pellita* open forest.**
7.12.5		**open forests on hill**	***Eucalyptus pellita* ± *Corymbia intermedia* open forest, or *Acacia mangium* and *Lophostemon suaveolens* open forest (or vine forest with these species as emergents), on granites and rhyolites.**

	7.12.5a		*Eucalyptus pellita, Corymbia intermedia* and *C. tessellaris* open forest with *Acacia celsa, A. cincinnata, A. mangium* and *A. flavescens.*
	7.12.5b		*Eucalyptus pellita, Corymbia intermedia* and *C. tessellaris* open forest with *Acacia celsa, A. cincinnata, A. mangium* and *A. flavescens*, with a very well developed vine forest understorey.
	7.12.5e		*Corymbia intermedia, Eucalyptus pellita, E. tereticornis, C. tessellaris* and *C. torelliana*, open forest to woodland with *Acacia celsa, A. mangium, Lophostemon suaveolens* and *Syncarpia glomulifera.*
	7.12.5e		*Acacia mangium* and *Lophostemon suaveolens* open forest with emergent *Eucalyptus pellita, Corymbia tessellaris*, and *C. intermedia.*
	7.12.5h		*Melaleuca viridiflora*, and *Lophostemon suaveolens* woodland.
	7.12.5i		*Imperata cylindrica, Sorghum nitidum* and *Mnesithea rottboellioides* grassland.
7.12.9	7.12.9	**acacia on hills**	***Acacia celsa* open to closed forest.**
7.12.11		**rainforest on hills**	**Simple notophyll vine forest and notophyll semi-evergreen vine forest of rocky areas and talus, of moist granite and rhyolite foothills and uplands.**
	7.12.11b		Simple notophyll vine forest.
7.12.17	7.12.17	**open forests on hills**	***Corymbia torelliana* open forest usually with a well developed simple notophyll vine forest element.**
7.12.23		**open forests on hills**	***Corymbia intermedia* and/or *C. tessellaris* ± *Eucalyptus tereticornis* medium to tall open forest to woodland (or vine forest with these species as emergents), on coastal granite and rhyolite headlands and near-coastal foothills.**
	7.12.23a		*Corymbia intermedia* open forest to tall open forest.
	7.12.23b		*Corymbia intermedia* open forest to tall open forest with a very well developed vine forest understorey.
	7.12.23e		*Corymbia tessellaris* and *C. intermedia* open forest to tall woodland and open forest.
	7.12.23d		*Corymbia tessellaris* and *C. intermedia* open forest to tall woodland and open forest with a very well developed vine forest understorey.
	7.12.23e		*Eucalyptus tereticornis, Corymbia tessellaris, E. pellita, E. intermedia, Melaleuca dealbata, Lophostemon suaveolens, Acacia mangium* and *A. crassicarpa* woodland to low woodland.
	7.12.23f		*Eucalyptus tereticornis, Corymbia tessellaris, C. intermedia, E. drepanophylla, E. platyphylla, Lophostemon suaveolens* and *Acacia aulacocarpa* woodland to low woodland and low layered grassy woodland, with *Cycas media.*
7.12.24		**open forests on hills**	***Eucalyptus portuensis* and *Corymbia intermedia* open forest to woodland (or vine forest with *E. portuensis* and *C. intermedia* emergents), on wet and moist foothills and uplands on granite and rhyolite.**
	7.12.24a		*Eucalyptus portuensis, Corymbia intermedia, E. drepanophylla, E. platyphylla, E. tereticornis, C. tessellaris, Lophostemon suaveolens, Syncarpia glomulifera* open forest to woodland.
7.12.26		**open forests on hills**	***Syncarpia glomulifera* ± *Corymbia intermedia* ± *Allocasuarina* spp. closed forest to woodland, or *Lophostemon suaveolens, Allocasuarina littoralis, C. intermedia* shrubland, (or vine forest with these species as emergents), on exposed ridgelines or steep rocky slopes.**
	7.12.26d		*Syncarpia glomulifera, Corymbia intermedia, Allocasuarina littoralis, Banksia aquilonia, Acacia flavescens* woodland to low woodland with *Xanthorrhoea johnsonii.*
7.12.28		**woodland on hills**	***Eucalyptus platyphylla* ± *E. drepanophylla* ± *Corymbia* spp. open woodland to open forest on granite and rhyolite.**
	7.12.28a		*Eucalyptus platyphylla, E. drepanophylla, Corymbia intermedia, Lophostemon suaveolens* woodland to low woodland to open forest.
	7.12.28b		*Eucalyptus platyphylla* woodland to open woodland.
7.12.29		**open forests on hills**	***Corymbia intermedia* and/or *Lophostemon suaveolens* open forest to woodland ± areas of *Allocasuarina littoralis* and *A. torulosa*, of uplands, on granite and rhyolite.**
	7.12.29a		*Corymbia intermedia, Eucalyptus tereticornis, E. drepanophylla* open forest to low open forest and woodland with *Allocasuarina torulosa, A. littoralis, Lophostemon suaveolens, Acacia cincinnata, A. flavescens, Banksia aquilonia* and *Xanthorrhoea johnsonii.*

7.12.40		**rainforest on hills**	**Closed vineland of wind disturbed vine forest, on granites and rhyolites.**
	7.12.40a		Open areas in vine forests, dominated by sprawling vines, commonly *Merremia peltata* and a number of other vine species, presumed to mostly originate from cyclone damaged Type 2a forests (where the entire canopy has been destroyed.).
	7.12.40b		Mesophyll to notophyll vine forest suffering from extreme wind damage where at least half the canopy has been destroyed.
7.12.53		**open forests on hills**	***Corymbia clarksoniana* ± *C. tessellaris*, ± *Eucalyptus drepanophylla* ± *C. intermedia* open forest to woodland, or *E. drepanophylla* woodland, of moist to dry lowlands, foothills and uplands on granite and rhyolite.**
	7.12.53a		*Corymbia clarksoniana* woodland to open forest.
	7.12.53b		*Corymbia clarksoniana, C. tessellaris,* ± *Eucalyptus drepanophylla, E. tereticornis, E. platyphylla, Lophostemon suaveolens* and *C. dallachiana* woodland and open forest.
	7.12.53c		*Eucalyptus drepanophylla* open woodland.
7.12.54		**shrubland on hills**	**Complex of shrublands and low open forests on wind-exposed granite and rhyolite coastal headlands and islands, on skeletal soils.**
	7.12.54g		Bare rock.
7.12.59	7.12.59	**open forests on hills**	***Eucalyptus leptophleba* and *Corymbia clarksoniana* open forest to woodland.**
7.12.60		**teatree on hills**	***Melaleuca viridiflora* ± *Corymbia clarksoniana* ± *Eucalyptus platyphylla* woodland to open forest, on granite and rhyolite.**
	7.12.60a		*Melaleuca viridiflora* woodland.
	7.12.60b		*Corymbia clarksoniana*, and/or *C. intermedia*, ± *Lophostemon suaveolens* open woodland to low open woodland with a prominent secondary tree layer of *Melaleuca viridiflora*, and often with *Xanthorrhoea johnsonii* in the ground stratum.
	7.12.60c		*Melaleuca quinquenervia* woodland, open forest or shrubland.
7.12.61		**open forests on hills**	***Eucalyptus tereticornis* ± *E. granitica* woodland to open forest of moist and dry foothills and uplands on granite and rhyolite.**
	7.12.61a		*Eucalyptus tereticornis* open forest to tall open forest and woodland. Includes communities ranging from those dominated by *E. tereticornis* to mixtures of that species with *Corymbia intermedia, E. drepanophylla, Lophostemon suaveolens* and *Allocasuarina torulosa.*
7.12.66		**shrubland on hills**	**Exposed rocky slopes on granite and rhyolite, with *Lophostemon confertus* low shrubland or low to medium closed forest.**
	7.12.66c		Bare rock.
11.3.30	11.3.30b	**woodland**	***Eucalyptus crebra, Corymbia dallachiana* woodland on alluvial plains.**
3.3.2	3.3.2a	**woodland**	**Semi-deciduous mesophyll/notophyll vine forest. Occurs on alluvia.**

Information for authors

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C. P. Kahler, and C. N. Appelman
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CD-ROM to accompany Kemp et al., Pre-clearing vegetation of the coastal lowlands of the Wet Tropics Bioregion, North Queensland (pages 285–329, this issue).

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